DESIGN ANALYSIS OF AUTOMATIC ENVIRONMENTAL CONTROL SYSTEMS IN GENERAL MOTORS AUTOMOBILES

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THESIS

ABSTRACT

DESIGN ANALYSIS OF AUTOMATIC ENVIRONMENTAL CONTROL SYSTEMS IN GENERAL MOTORS AUTOMOBILES

By

Randy J. Wheeler

In recent years, the proportion of new cars built in the United States with factory-installed air conditioning systems has risen to greater than 40 percent. In addition, automatic control air conditioning systems are being built in increasing numbers. It is the purpose of this work to compare the three completely different systems now built in General Motors automobiles on the basis of production and service characteristics to aid Oldsmobile Division in setting future design goals. This thesis is one of the final stages in a five year work-study cooperative program involving four years study at General Motors Institute and one year of graduate study at Michigan State University.

There are three different automatic air conditioning systems: the Oldsmobile Comfortron, the Buick Automatic Climate Control, and the Pontiac Automatic Temperature Control. The Comfortron is an electrical-vacuum system using electrical sensing and modulated vacuum control. The Automatic Climate Control is a mechanical-vacuum system using bi-metal sensing elements and vacuum control. The Automatic Temperature Control is an electrical-mechanical system using electrical sensing elements and electric motor control.

The thesis draws conclusions and makes recommendations pertinent to future developments at Oldsmobile.

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Randy J. Wheeler

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INTRODUCTION

Air conditioning systems were first installed in automobiles in the years before World War II. At first these installations were made on an individual basis by garages. The first factory-installed air conditioning systems were in Packards. All of these early systems had the evaporator installed in the trunk.

The 1954 Pontiac was the first General Motors automobile to have the complete system in the front of the car. The entire automotive industry went to that system in the years shortly following that time and the basic air conditioning system has remained much the same since then, with only evolutionary changes.

One important change came with the advent of the air-mix system. All previous systems used a water valve control to modulate the heater temperature and they had a completely separate air conditioning system with separate duct work. The air-mix system integrated the heater and air conditioning systems and used the principle of mixing heated and cooled air in appropriate proportions to achieve the desired outlet temperature. The air is then directed by door valves to the appropriate ducts.

This system has the following advantages:

1. More rapid temperature changes.
2. More precise temperature control.
3. Ability to dehumidify heated air to prevent fogging (especially useful on cool, humid days).

The 1964 Cadillac Comfort Control was the first fully automatic system. All previous systems had required driver control of temperature, fan speed, and mode (heater or air conditioning). The Cadillac system was an electrical-vacuum control system which was programmed to perform these functions. Its main design requirements were:

1. To maintain passenger compartment comfort under all climate and engine operating conditions.

2. To relieve the driver from adjusting controls thereby releasing his full attention to the task of driving.

3. To achieve the desired comfort level as rapidly as possible.

Since then, all three major automobile manufacturers have developed automatic systems. General Motors alone has had no less than four completely different systems in production with others under development.

Figures from the March 5, 1969, issue of "Automotive Industries" Magazine illustrate the growing role of air conditioning systems in the automotive industry:

TABLE 1

AIR CONDITIONING
FACTORY INSTALLATION FIGURES

Model Year	Units	% of Total Production
1965	2,060,675	23.30
1966	2,522,193	29.30
1967	2,905,750	38.40
1968	3,519,373	43.26

These figures indicate almost double the installation rate by percent of only four years ago. This is an impressive growth record for an option which is second to none in price except some engine options. The option prices range from $324 on an American Motors Rambler to $516 on a Cadillac.

With increased demand for air conditioning systems, customer interest is also likely to go toward the more sophisticated automatic systems. Herein lies the motivation for this research. The purpose of this report is to provide Oldsmobile with some guidelines for future automatic air conditioning systems. It makes some pertinent conclusions about the systems now produced in General Motors and some recommendations for future systems.

The scope of this thesis was originally to include the cost of each system. This was found to be impractical, however. Though it is to be admitted that the cost is of prime importance from an executive standpoint, it must be said that in this instance cost is not likely to be a good basis of comparison. Consider the following examples in support of this assertion.

The Cadillac Comfort Control and the Oldsmobile Comfortron are virtually identical systems in theory of operation. Consider the blower speed programs of each system. The Cadillac system has three normal control lever positions, LO-AUTO-HI. The Oldsmobile system has two

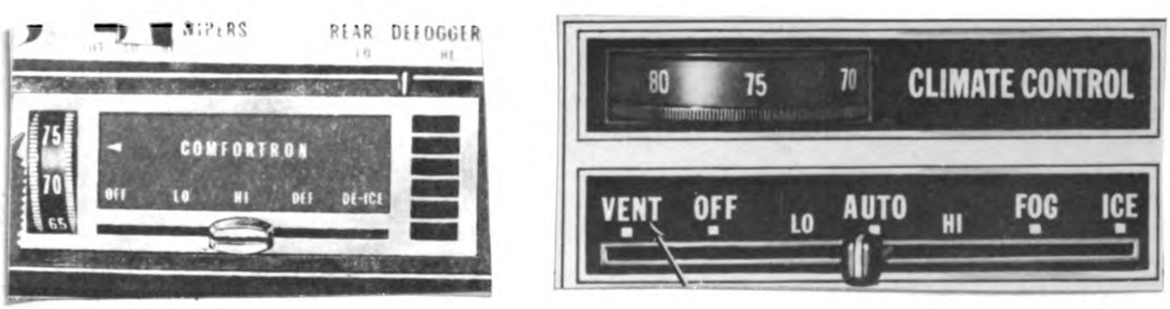

FIGURE 1 COMFORTRON AND AUTOMATIC CLIMATE CONTROL PANELS

positions, LO-HI, as shown in Figure 1 (Page 3). In any of these positions, each system is in automatic temperature control. The Cadillac system runs in LO at one low blower speed, in AUTO at one of four automatically selected blower speeds, and in HI at one high blower speed. In contrast, the Oldsmobile system runs in LO in a range of five automatically selected low blower speeds and in HI in another range of five high blower speeds. This difference is the result of engineering judgment and executive decision. There are also other differences between the systems, but this difference will serve to illustrate the point.

Another example is a difference between the Pontiac Automatic Temperature Control (ATC) and the Oldsmobile Comfortron. These systems operate on completely different principles. By design, the Oldsmobile system operates in two modes: heater mode or air conditioning mode. The Pontiac ATC operates in three modes: heater mode, air conditioning mode, or bi-level mode. Bi-level mode is a transitional mode between heater and air conditioning in which air is directed through both heater and air conditioning outlets.

Each of these illustrative differences between systems is small individually, but when one considers the total difference between the systems, the picture changes.

Though the systems are supposedly comparable, they are each the product of individual engineering judgment and decision and are thereby different devices.

If the systems supported identical features, then a cost comparison could be extremely meaningful. But, since the systems are so different in the number and nature of features that they support the significance of a direct dollar-for-dollar comparison is lost.

The scope of this thesis has, therefore, been narrowed to cover the following considerations:

I. PRODUCTION INSTALLATION ADAPTABILITY

   A. Labor time
   B. Production repair considerations
   C. Number of discrete components and connections

II. SERVICEABILITY

   A. Service problems
   B. Trouble shooting considerations
   C. Component accessability

The following systems were chosen because they represent a cross section of the three different automatic systems now produced in the General Motors Corporation. They are:

1. Oldsmobile Comfortron

   This system is a descendant of the original Cadillac system. It is closely related to the systems now built by Chevrolet and Cadillac and uses themistor sensing and vacuum actuation.

2. Buick Automatic Climate Control

   This system is built only by Buick. It uses bi-metal temperature sensing and vacuum actuation.

3. Pontiac Automatic Temperature Control

   This system is produced only by Pontiac. It uses themistor temperature sensing and electric motor servo actuation.

Other systems which are now under development were considered for inclusion in this list but since information is incomplete on these systems, they were not included.

This work was undertaken under the auspices of and in cooperation with the Product Engineering Department of Oldsmobile Division of

General Motors Corporation. It is part of the final phase of a five year engineering program involving a four year cooperative work-study program at General Motors Institute and a one year graduate program at Michigan State University. It is intended to be used, in part, as a guide to future product developments at Oldsmobile.

The following chapters describe each of the above systems individually and in detail. Following that, a comparison of the systems is made with regard to their production and service characteristics. Finally, some conclusions and recommendations are made.

I. OLDSMOBILE COMFORTRON

Oldsmobile first produced the Comfortron during the 1966 model year. It was a direct descendant of the Cadillac Comfort Control, the original automatic air conditioning system, first produced in 1964. This system was engineered by Delco Radio Division, General Motors Corporation. The present Comfortron is an evolved version of the 1964 system in that only small changes have been made in the system to improve its performance. This chapter describes the 1969 model year Comfortron in detail as it is installed in the Oldsmobile "98" series.

The Comfortron is an electrical-vacuum, feedback servomechanism. It is designed to assume the task of maintaining the enviromental temperature within the car at some preset comfort level between 65° and 85°F.

The system is designed to support the following operational features in order to attain and maintain the temperature level.

1. Outlet air temperature - from full heated air to full cooled air
2. Fan speed - give unique fan speeds in each of two ranges
3. Mode - outlet air distribution
    a. Heater
    b. Air conditioning
    c. Defrost
4. Inlet Air Source
    a. 100% outside air

   b. 20% outside air - 80% recirculated air

5. Dehumidification - at ambient temperatures above 33°F

6. System start-up delays

   a. Cold weather start-up delayed until engine coolant temperature reaches 120°F and cold air from ducts purged

   b. Warm weather immediate start-up

7. Deice - start-up delays are by-passed and system drives to full heat, high speed fan.

8. Heater water shut-off - to enhance maximum cooling performance

9. Output stabilization - Under insufficient vacuum supply conditions (e.g., upon heavy acceleration) the system locks to prevent erroneous output changes.

The information flow in the system is diagramed in Figure 2 (Page 9). The diagram is specifically about the Oldsmobile Comfortron but the Buick Automatic Climate Control and Pontiac Automatic Temperature Control, described in the following two chapters, operate using the same basic information network. These two systems are, however, different in the features which they support to achieve the desired control.

Information entering the control mechanism represents prevailing tempterature conditions and the driver's wishes. The control mechanism reacts, producing a predetermined set of output conditions such as outlet air temperature, fan speed, etc., in order to match the conditions with the driver's wishes. Most of the output takes the form of conditioned air entering the system. There is, however, a minor feedback loop through the temperature door potentiometer. This loop feeds information to the control mechanism representing outlet temperature. The same information would eventually reach the control in terms of in-car temperature, but, since in-car temperature changes so slowly,

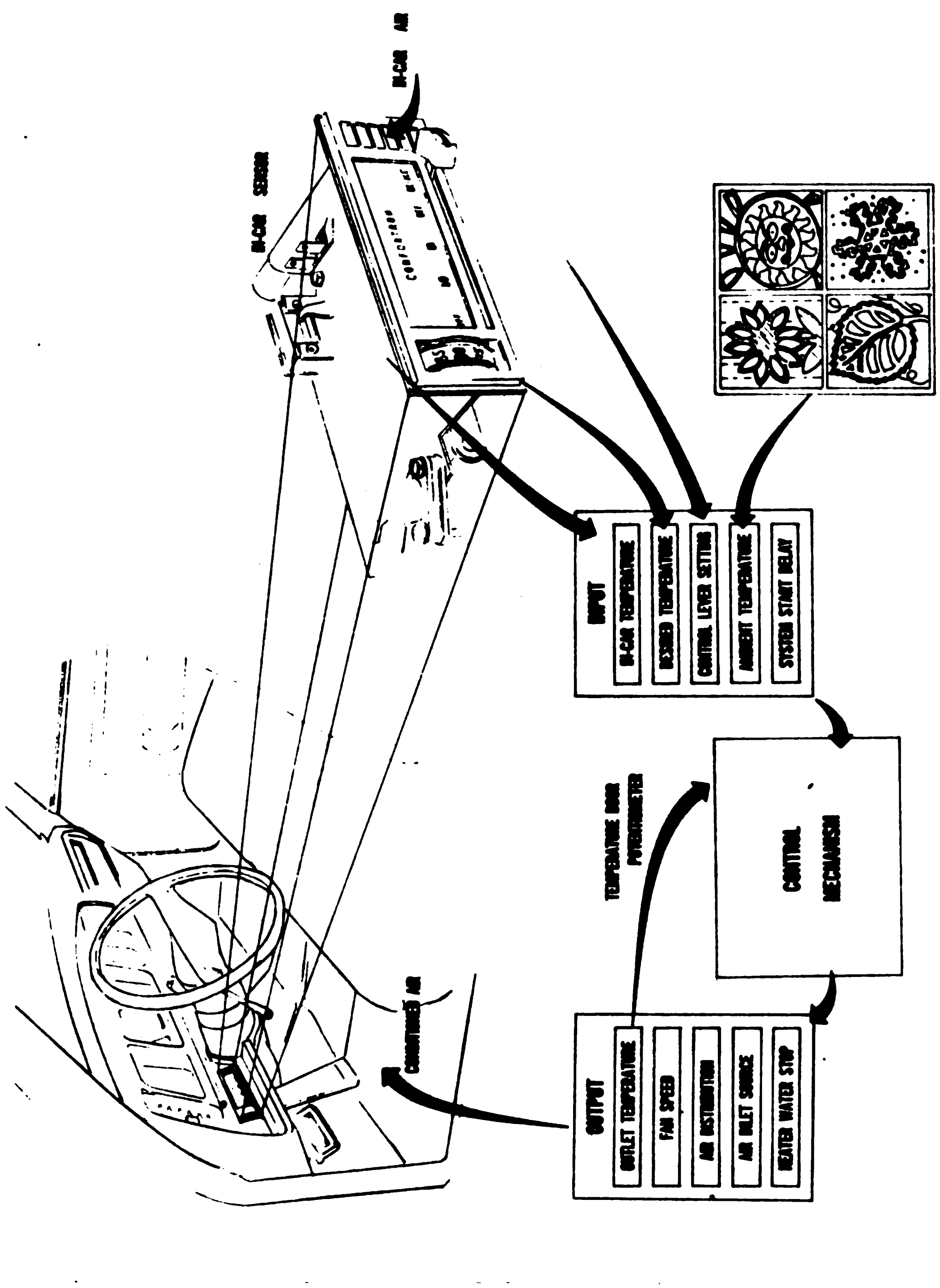

FIGURE 2 INFORMATION FLOW THROUGH THE COMFORTRON SYSTEM

the desired temperature may be overshot. Therefore, this feedback loop allows the system to approach the desired in-car temperature in a more nearly optimum manner. It can be noted that some systems also perform the same function by electrically measuring actual outlet air temperature. This leads to difficulty in that different outlets are used under different circumstances so that no one outlet consistently represents outlet temperature at all times.

Repeating, the main information flow is through the in-car air temperature. The in-car temperature is affected, however, in other ways than just by the output of the system. Radiant energy from the sun enters through the windows and convection and conduction occurs especially at high road speeds. These influences are translated into changes in overall in-car temperature thereby effecting a compensating change in the state of the control mechanism.

The control system also receives information which controls the initial start-up of the system. At ambient temperatures below about 70°F, when the system would normally demand heat at start-up, the system will not start automatically until the engine coolant has reached a temperature of 120°F. Until then, no heat is available to warm the car so there is little point in starting the system blowing cold air. A delay of about 15 seconds is made to allow time for the heater core to warm up and for cold air in the ducts to be purged slowly to prevent an unpleasant cold blast. In warm weather, when cooled air is desired at start-up, the system starts almost immediately.

The following is a detailed description of each of the components in the Comfortron Control System. The components are connected as shown in the following figure, Figure 3 (Page 11) - Vacuum Circuit Diagram, and

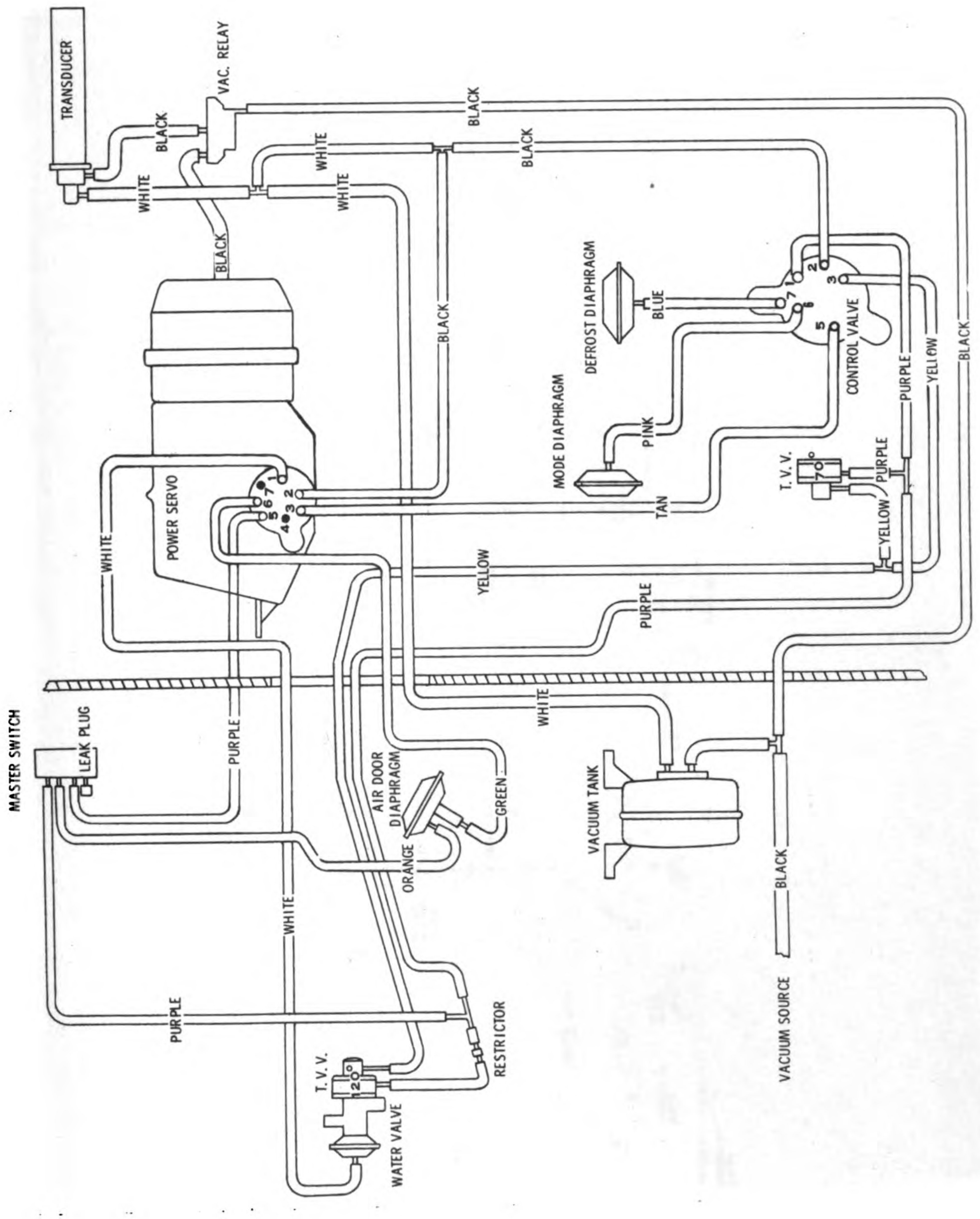

FIGURE 3 COMFORTRON VACUUM CIRCUIT DIAGRAM

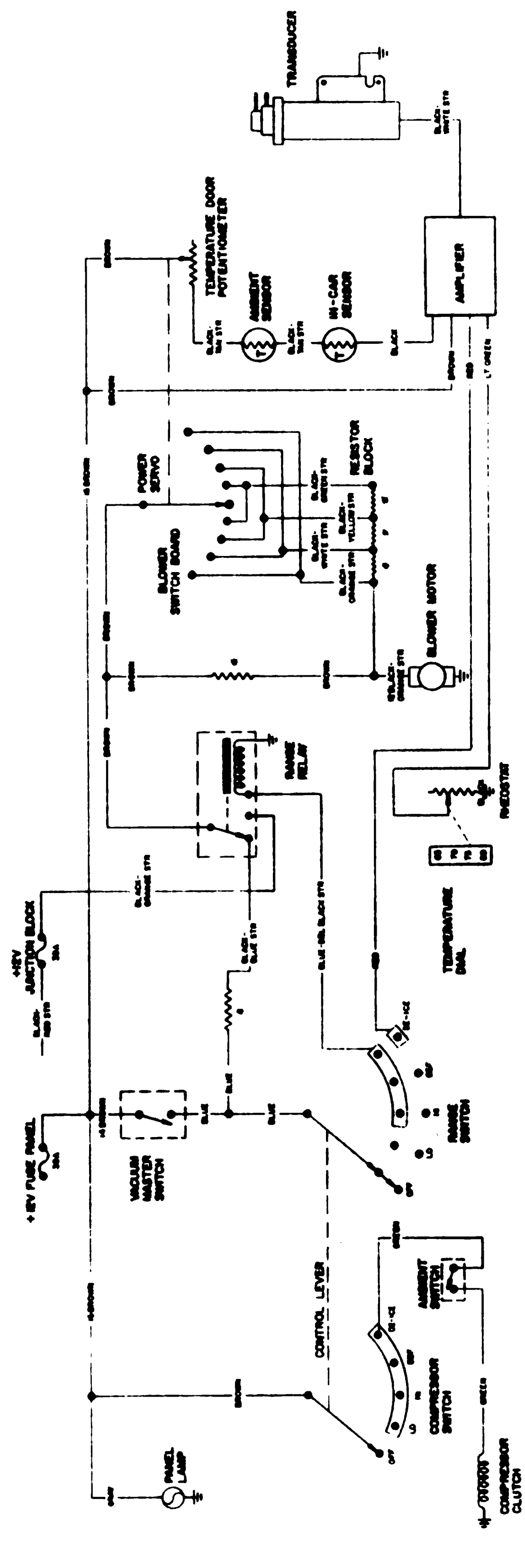

FIGURE 4 COMFORTRON ELECTRICAL CIRCUIT DIAGRAM

Figure 4 (Page 12) - Electrical Circuit Diagram. Reference to these figures as well as other figures as sited in the text will aid in understanding the operation of the system.

<u>Control Panel</u> (Figures 5 [Page 13] and 6 [Page 14])

The control panel, located in the instrument panel to the left of the steering column, contains the following:

1. Control lever, vacuum valve, and switches
2. Temperature control dial and rheostat
3. Amplifier
4. In-car sensor
5. Thermostatic vacuum valve (Inside car)

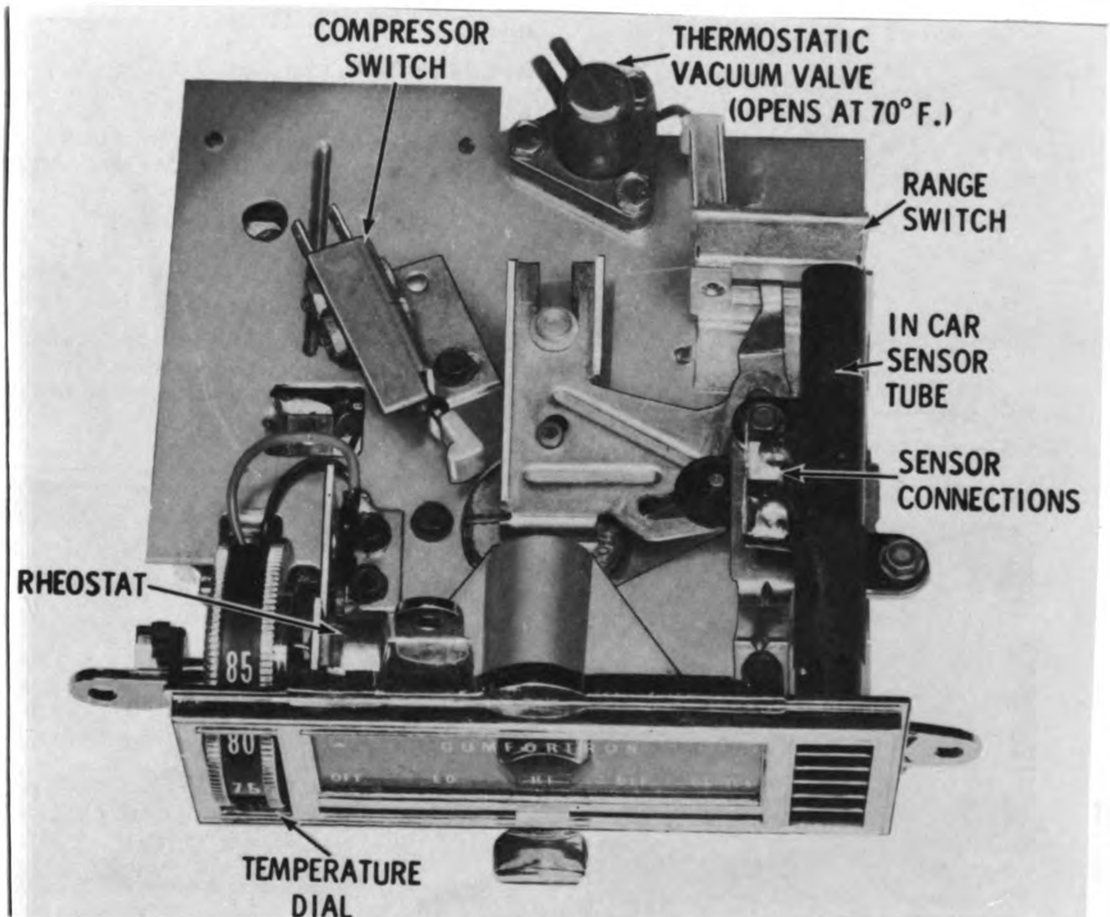

FIGURE 5 COMFORTRON CONTROL PANEL

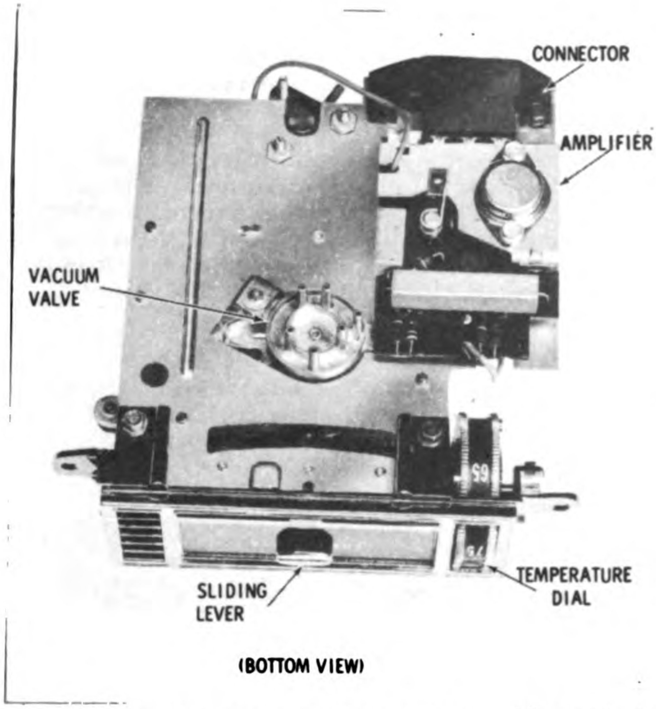

FIGURE 6 COMFORTRON CONTROL PANEL - BOTTOM VIEW

The control elements (#1 and #2 above) will be described here. The others are described under their own headings.

The control lever can be placed in five positions:

OFF - With the control lever in OFF position, the vacuum is shut off and the system is inoperative.

LO - With the control lever in LO position, vacuum is supplied to the system through the vacuum valve (Figure 6). The system will start if the engine coolant is above 120°F, or the inside of the car is 70°F. The blower will automatically run in one of the five low range blower speeds and the temperature will be automatically controlled by the temperature control setting, and the outside and inside air temperatures.

HI - With the control in HI position, the system will operate just as it does in LO position except that the blower will operate in the five high range blower speeds.

DEF - With the control lever in DEF position, the system will operate just as it does in HI position except that the mode door directs air only to the heater ducts and the defrost door opens. Approximately 80%

of the air goes to the defroster outlets and 20% goes to the heater outlets. Note that the system is still on automatic temperature control so that either hot or cold air may come from the defroster outlets as the system dictates.

DE-ICE - With the control lever in DE-ICE, vacuum is immediately applied to the system regardless of air or engine coolant temperatures. A contact on the range switch closes forcing the system to full heat and highest blower speed. Note, the system is no longer on automatic control. This is the only lever position in which the system will start immediately, irrespective of any other condition.

The vacuum valve is positioned by the control lever. It controls the vacuum supply and directs vacuum as necessary to make the system operate in the desired way.

There are also two switches on the control panel. The compressor switch supplies power to the compressor clutch circuit when the control lever is in any position except OFF. The ambient switch (described later) then turns on the compressor at any outside air temperature above 35°F. The range switch controls high and low range blower speeds and forces the system to full heat in DE-ICE position as described before.

The temperature dial is calibrated in temperatures between 65°F and 85°F. It should be set at a comfortable temperature (about 72°F normally, but it may vary with individual preference) and only small changes should be necessary to maintain comfort. The system will automatically work at maximum effort to attain and hold the desired temperature.

The rheostat is directly coupled to the temperature dial. It is a resistance input to the amplifier used to set the desired temperature.

SENSORS

There are two temperature sensing elements in the system; they are in the in-car air sensor and the ambient (outside) air sensor. The temperature door position potentiometer, Figure 7 (Page 16), also serves as a temperature indicating device in that it indicates temperature door position, which is analog to outlet temperature.

The temperature door potentiometer, mounted on the Power Servo, is connected to the temperature door linkage and mechanically provides resistance in the sensor circuit in relation to the discharge temperature.

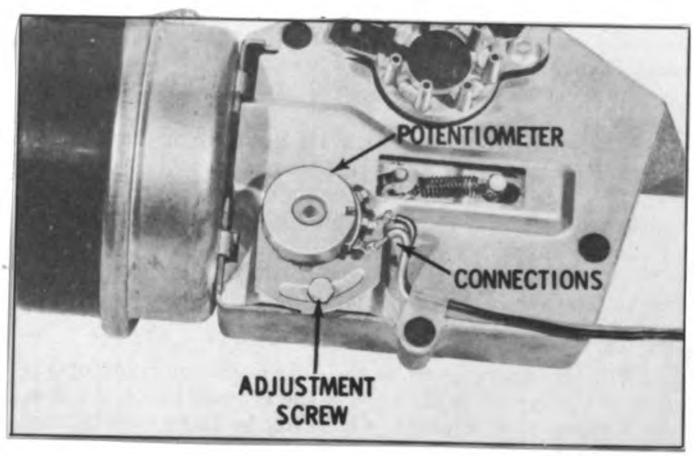

FIGURE 7 TEMPERATURE DOOR POTENTIOMETER

The in-car ambient sensors are thermistors, temperature sensitive resistors, whose electrical resistance varies inversely with temperature. That is, as their temperature goes up, their resistance goes down. Table 2 (Page 17), shows the relationship between sensor temperature and electrical resistance.

TABLE 2

SENSOR RESISTANCE VS. TEMPERATURE

CHECKING SENSOR RESISTANCE

Approximate Resistance in Ohms (±5%)

Temp.	Outside Sensor Ohms	Sensor on Control Ohms
60°	44	95
65°	41	86
70°	38	76
75°	36	68
80°	34	60
85°	32	55
90°	30	50
95°	27	45
100°	23	40

The in-car sensor, located in the control panel, Figure 5 (Page 13), has air from the inside of the car drawn over it through a grill in the panel so that it senses in-car temperature.

The ambient sensor mounted in the blower inlet duct, Figure 8 (Page 17), senses the temperature of the outside air entering the system.

Figure 16

FIGURE 8 AMBIENT SWITCH AND AMBIENT SENSOR

The sensors and the temperature door potentiometer are wired in series with the temperature dial rheostat to form a voltage divider network. As temperatures vary, the total series resistance changes, supplying a variable voltage to the input of the amplifier. Changes in in-car temperature produce a compensating change in the system output to return the in-car temperature to the desired level. Changes in ambient temperature are sensed so as to quickly affect changes in system output to compensate for differences in inlet air temperature and also for changes in conduction and convection losses.

AMPLIFIER

The amplifier, mounted on the control panel, Figure 6 (Page 14), is a two transistor, Direct Current, amplifier. Its input is the resistance from the temperature rheostat and the sum of the resistances in the sensor string. Its output is a variable current signal to the transducer.

It also has a special input controlled by a contact on the range switch, which forces the system to full heat in DE-ICE operation.

TRANSDUCER

The transducer, Figure 9 (Page 19), is an electrical-vacuum device which converts the current output signal from the amplifier into a regulated vacuum signal which activates the Power Servo.

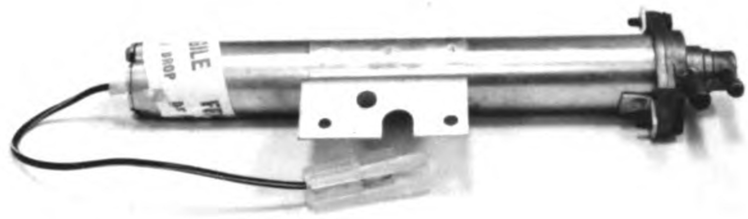

FIGURE 9 TRANSDUCER

It contains a force operated vacuum valve which is activated by a wire loop element as shown in Figure 10. The wire element is a special

FIGURE 10 TRANSDUCER DIAGRAM

material with a high thermal expansion coefficient. It is heated by the current signal from the amplifier.

The valve balances two forces, the force due to the difference between atmospheric pressure and the partial vacuum in the system, and the force due to the wire element. High current levels heat the element causing it to expand and relax the force on the valve. The opposite occurs at low current levels.

At high current levels, the regulated vacuum is high and at low current levels, regulated vacuum is low.

POWER SERVO

The power servo, Figure 11, is mounted on the top, right side of the heater assembly. It contains a vacuum diaphram assembly which is controlled by the regulated vacuum from the transducer.

The vacuum diaphram operates the temperature door linkage, and the blower speed switch which is a circuit board and wiper contact assembly, and a rotary vacuum switch.

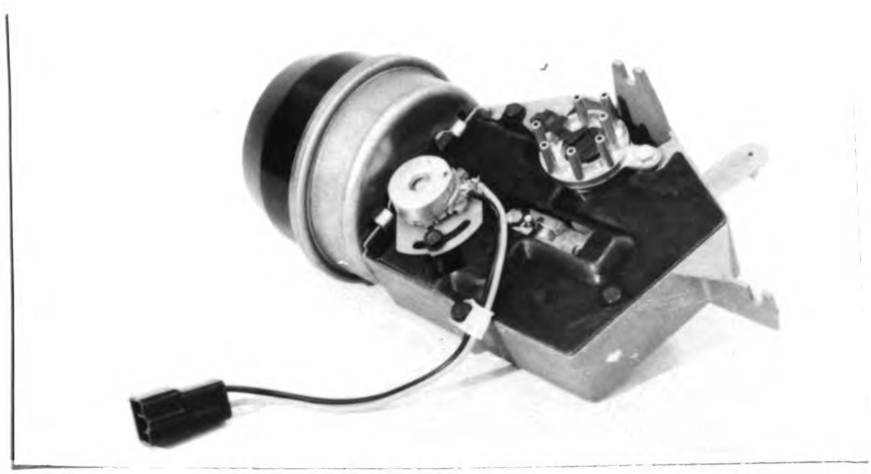

FIGURE 11 POWER SERVO

The power servo normally operates near center travel of the vacuum diaphram travel. The temperature door is positioned at about mid-travel and the blower speed is on low. Increased vacuum drives the power servo toward higher heat. The temperature door assumes a position which mixes more warmed air and less cooled air. The vacuum valve forces heater mode which distributes air to the heater outlets if the system was not in heater mode already. As the servo moves, father toward full heat, the blower speed switch turns the blower to four successively higher speeds until at full heat, the blower is at full speed.

Reduced vacuum moves the vacuum diaphram the other way. Air conditioning mode is assumed wherein outlet air is distributed to the air conditioning outlet. Again, higher and higher blower speeds are selected. At full cold position, the vacuum switch turns off the heater water valve to enhance the maximum cooling capability of the system.

As previously described, the temperature door potentiometer is mounted on the power servo.

<u>THERMOSTATIC VACUUM VALVE (Inside car)</u> Figure 5

This vacuum valve, mounted on the control panel, opens to start the system whenever the in-car temperature is above 70°F. Figure 12 (Page 22) shows a typical thermostatic vacuum valve. It contains a special wax pellet which expands and contracts with changes in temperature.

FIGURE 12 TYPICAL THERMOSTATIC VACUUM VALVE

THERMOSTATIC VACUUM VALVE (WATER VALVE) Figure 14

This vacuum valve, mounted on the heater water valve, opens to start the system during cold weather when the engine coolant reaches 120°F. It is much the same as the Thermostatic Vacuum Valve on the inside of the car except that it is calibrated at 120°F instead of 70°F.

VACUUM MASTER SWITCH

This vacuum operated switch is mounted in the engine compartment adjacent to the blower motor. It applies power to the blower motor circuit when any of the following conditions are satisfied:

a. The Thermostatic Vacuum Valve on the heater water valve opens at 120°F engine water temperature, and the control lever is in HI or LO.

b. The Thermostatic Vacuum Valve on the control panel opens at 70°F in-car temperature and the control lever is in HI or LO.

c. The control lever is in DE-ICE position.

AMBIENT SWITCH Figure 8

The ambient switch, mounted with the ambient sensor in the blower inlet duct, is closed at temperatures above 35°F. It supplies power to the air conditioning compressor clutch whenever the system is on so that the air conditioning condenser will cool all incoming air to just above freezing to dehumidify it. At temperatures below freezing, the water from the air would freeze on the condenser so the air conditioning system is turned off.

RANGE RELAY

The range relay is located in the engine compartment next to the voltage regulator. When the control lever is set in the HI position, the range relay is energized, allowing the blower circuit to draw power directly from the junction block. This by-passes a fixed resistance in the LO range blower circuit and causes the blower to operate in one of the five, automatically selected blower speeds.

On cars with electric rear window defogger option, the range relay cannot be energized when the defogger is operating, preventing excessive power drain. The blower will then operate only in the low range speeds.

VACUUM RELAY

The vacuum relay, located in the passenger compartment, allows regulated vacuum to pass from the transducer to the power servo as long as sufficient engine vacuum is available to run the system. When the engine vacuum drops, as on hard acceleration or when climbing a hill, the vacuum relay seals, locking the power servo in its current position.

VACUUM TANK

The vacuum tank, located in the engine compartment, is used to store engine vacuum for the system. It has a check valve integral with it to prevent vacuum loss during periods of low vacuum supply.

ASPIRATOR Figure 13

The aspirator is attached to the bottom of the heater case and is located just ahead of the mode door. Whenever the blower motor is operating, air is drawn through the aspirator, aspirator hose, and in-car sensor tube located on the control (Figure 5 [Page 13]). The air is drawn over the in-car sensor through the instrument panel from the interior of the car.

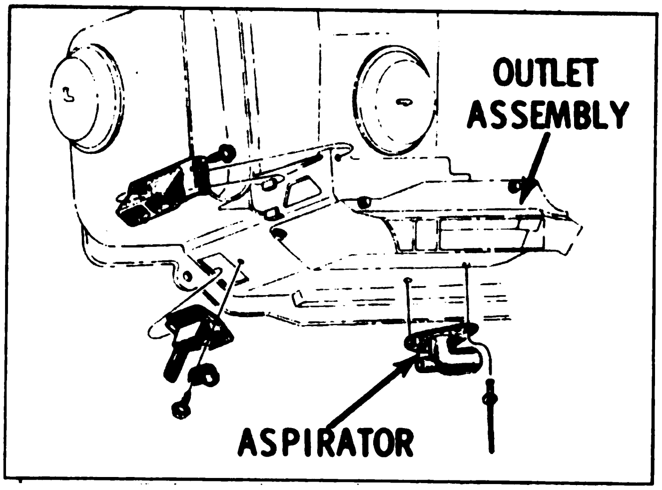

FIGURE 13 ASPIRATOR LOCATION

OUTSIDE AIR DOOR

The outside air door, mounted in the blower assembly in the engine compartment, controls the source of air entering the system. It is designed to assume three positions.

a. OFF - Door closes out outside air (control lever in OFF).

b. Production Recirculation - Door opens partially to admit approximately 80% recirculated air and 20% outside air (automatically selected by the system at full air conditioning to improve cool-down performance).

c. Full Outside Air - 100% fresh air.

DEFROSTER DOOR

The defroster door, located in the heater assembly, opens to pass about 80% of the heater air through the defroster outlets. It is designed to assume only two positions and should activate whenever the control lever is in DEF or DE-ICE.

MODE DOOR

The mode door, located in the heater assembly, directs air to either the air conditioning or heater ducts. It is designed to assume only these two positions.

TEMPERATURE DOOR

A door in the heater assembly, controlled by the Power Servo, controls the temperature of the air coming out of the air outlets. This door can assume any position from full heated air to full cooled air.

WATER VALVE Figure 14

The water valve, mounted in the engine compartment, is in the engine coolant to heater core line. It is actuated only when the system goes to full air conditioning and it stops engine coolant flow to the heater to improve cool-down performance.

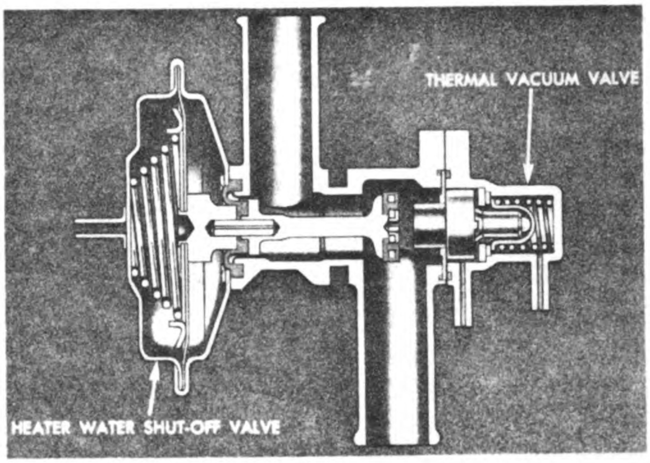

FIGURE 14 WATER VALVE DIAGRAM

LEAK DOWN PLUG

The leak down plug is a sintered metal plug attached to one part of the vacuum master switch. It is used to leak vacuum from the system when the supply is turned off, thereby opening the vacuum master switch and stopping the system.

RESTRICTOR PLUG

The restrictor plug is a calibrated restrictor in the purple hose to the Thermostatic Vacuum Valve. Its purpose is to delay blower motor start about 15 seconds, when the system starts, requiring heat output. This is done to allow the heater core time to warm. It also allows the air conditioning evaporator to cool to reduce outlet air humidity.

BLOWER RESISTORS

The blower resistors are a group of wire coil resistors mounted together near the blower assembly in the engine compartment. They are switched into and out of the blower motor circuit by the blower program switch in the power servo and by the range relay to provide the various blower speeds.

The following figures illustrate the positions and interconnections between the components in the car. Previous reference has been made to these figures and future referral will be helpful during description of sequence of operations of the system.

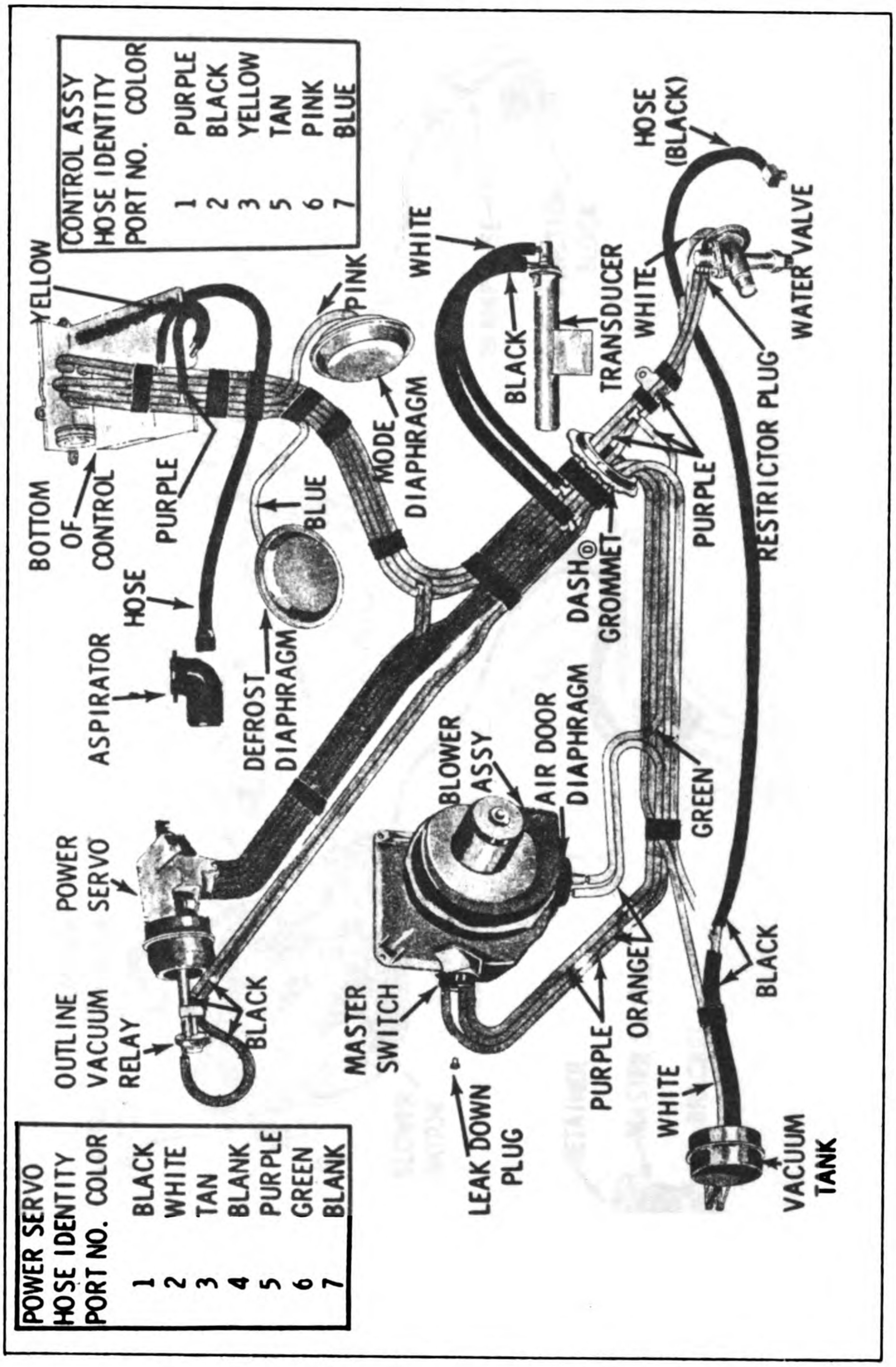

FIGURE 15 COMFORTRON VACUUM HOSE CONNECTIONS

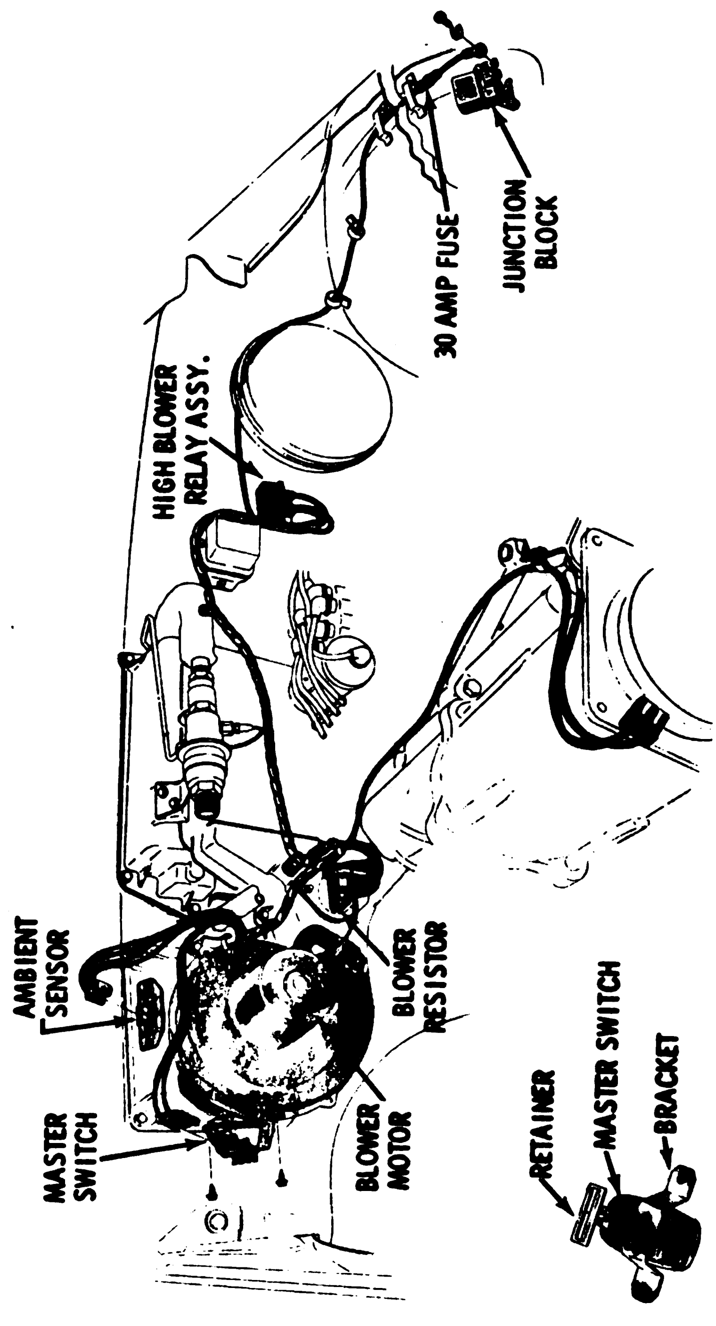

FIGURE 16 ENGINE COMPARTMENT CONNECTIONS

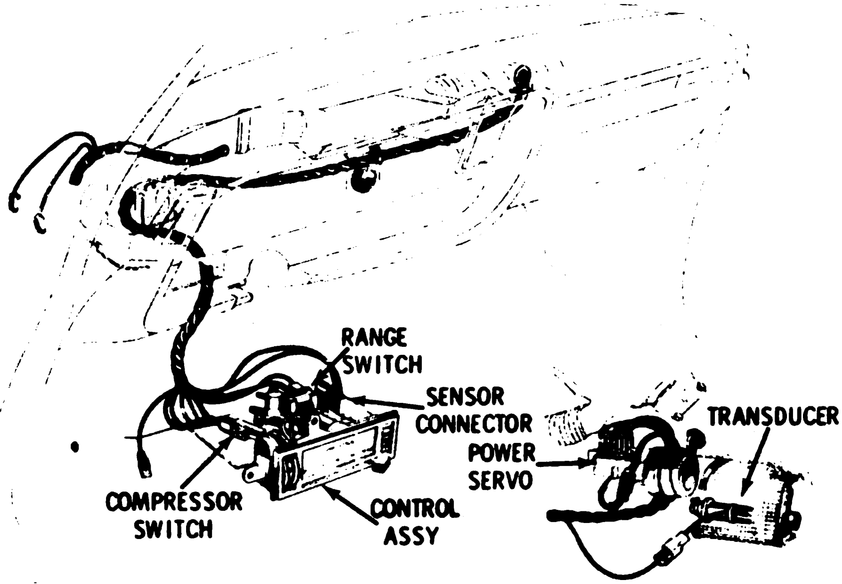

FIGURE 17 INSTRUMENT PANEL WIRING

For the purpose of illustration, the following sequences of operation are included in the text. These sequences are by no means meant to cover all possibilities. They will, however, lead to a greater understanding of the interaction of the components.

CASE 1

Initial Conditions

The car has been exposed to a temperature of 20°F for a period of time sufficient to allow the entire vehicle to stablize at that temperature.

Sequence of Operations

1. The driver enters the car, starts the engine, turns the Comfortron control lever to HI, sets the temperature dial to 72°F, and drives off.

2. Vacuum is supplied to both Thermostatic Vacuum Valves, but they are both closed so vacuum is not supplied through them to the Vacuum Master Switch or any of the door diaphrams.

3. Vacuum is supplied, however, to the Transducer whenever vacuum is available. Also, electrical power is supplied to the sensor string and amplifier. So, the control system senses the need for heat to warm the car to the desired temperature and drives the Power Servo to the full heat position. The temperature door is, therefore, in the full heat position, the vacuum is ready to set the mode door in heater mode position, and the fan speed switch is in the high speed position.

4. At some time, the engine coolant passing through the heater water valve, reaches 120°F and the Thermostatic Vacuum Valve mounted on the water valve opens. Vacuum is then applied to the master switch through the restrictor plug. The restrictor plug slows the closing of the electrical contacts in the master switch while allowing the outside air door to open. This is done to allow the cold air in the system to be purged slowly. The air conditioning evaporator also starts to cool, at ambient temperature above 35°F, reducing the outlet air humidity.

5. The vacuum level builds, after a few seconds, to where the electrical contacts close. This applies power to the Compressor Switch, Range Switch, and the Blower Circuit. The Compressor Switch would supply power to the compressor clutch except that the Ambient Switch is open at ambient temperatures below 35°F. Since the control lever is in HI, the range switch applies power to the range relay, closing it and placing the blower in high range.

6. The blower starts on highest speed with the temperature door in full heat position and the car begins to warm.

7. Eventually the interior of the car warms and the system begins to sense a balanced condition between desired and actual in-car temperature. The Transducer reduces the vacuum level to the Power Servo which moves the temperature door away from full heat and begins reducing the fan speed.

8. The system finally senses that the desired temperature has been reached, the fan speed is on low speed, high range, and the temperature door is near center with the air coming out the heater ducts just warm enough to maintain the desired temperature.

9. The system has reached the desired temperature about as fast as possible without overshooting the goal. It continues to sense small differences between desired and actual temperatures and makes appropriate output changes to eliminate the difference. The driver may opt at any time to place the control lever in LO which will place the blower speed in low range, but the speed within that range will still be automatically selected.

CASE 2

Initial Conditions

The car has set in the sun with the windows closed for a period of time at an ambient temperature above 90°F. The interior of the car has reached high temperatures and the interior surfaces are uncomfortable to touch.

Sequence of Operations

1. The driver enters the car, lowers the windows, starts the engine, sets the control lever at HI, and drives off.

2. The Thermostatic Vacuum Valve in the car is open already, so vacuum is applied to the master switch, starting the fan in high range.

3. The system senses the need for cooled air and so reduces vacuum to the Power Servo driving it to full cold position.

4. The vacuum valve on the Power Servo selects air conditioning mode and the blower speed moves to highest speed. The ambient switch is closed, starting the compressor.

5. The vacuum switch, at full cold position, moves the outside air door to recirculate position so air recirculates through the system and cools more efficiently. It also closes the water valve to stop heated water to the heater core so that less heat is transferred into the system, thereby enhancing the cooling capacity of the system.

6. As the system starts to cool, the driver shuts the windows.

7. The temperature begins to approach the desired temperature and the system begins to throttle back, first by opening the water valve, then by going from recirculate to full outside air.

8. The fan speed reduces and the temperature door moves toward center as the temperature approaches the desired temperature.

9. Finally, with the desired temperature reached, the system begins to make small changes necessary to maintain the desired temperature.

II. BUICK AUTOMATIC CLIMATE CONTROL

Buick first produced the Automatic Climate Control during the 1966 model year. The system was designed and built by Harrison Radiator Division of General Motors Corporation specifically for Buick.

The system was a thermo-mechanical system using capillary sensing elements. These sensors are glycol filled tubes located so as to sense temperatures in three locations: in-car, ambient, and duct outlet. The glycol expanded and contracted with temperature changes and the net effect of all three sensors was used to drive a piston. The system then employed mechanical and vacuum means to adjust outlet air temperature and fan speeds to achieve the desired in-car temperature.

The following model year, 1967, Buick started using a different system which was also designed and built by Harrison Radiator Division. This system is the predecessor of the current system. This chapter describes the 1969 model year Buick Automatic Climate Control System.

The Automatic Climate Control is a mechanical, vacuum-feedback control system. It is designed to be capable of maintaining the environmental temperature within the car at any desired temperature between 65°F and 85°F.

The system supports the following features as means to attaining and keeping the desired temperature level.

1. Outlet air temperature - from full heated air to full cooled air.

2. Fan speed - five different fan speeds in each of two ranges.

3. Mode - outlet air distribution

    a. Heater
    b. Air conditioning
    c. Defrost

4. Inlet Air Sources

    a. 100% outside air
    b. 20% outside air - 80% recirculated air

5. Dehumidification - at ambient temperatures above 35°F.

6. System start-up delays

    a. Cold weather start-up delayed until engine coolant temperature reaches 100-120°F and until cold air is purged from ducts.

7. De-ice - start-up delays are by-passed and fan goes to highest* speed, but system remains in automatic temperature control.

8. Heater water shut-off - to enhance maximum cooling performance.

9. Output Stabilization - During periods of low vacuum supply (e.g. upon heavy acceleration) the system locks to prevent erroneous output changes.

Reference to Figure 2 (Page 9) will show basically how the control information flows through the Automatic Climate Control. As was mentioned before, that diagram is specifically about the Oldsmobile Comfortron system, but it also applies to the Automatic Climate Control with the following exception. No feedback loop exists to indicate outlet air temperature. This function is performed by the temperature door potentiometer in the Oldsmobile system. The information flows are otherwise the same.

The following is a specific description of each of the components in the Buick Automatic Control, Figure 18 and Figure 19 (Pages 35 and 36) the vacuum and electrical circuit diagrams on the following pages show the interrelation of the pieces.

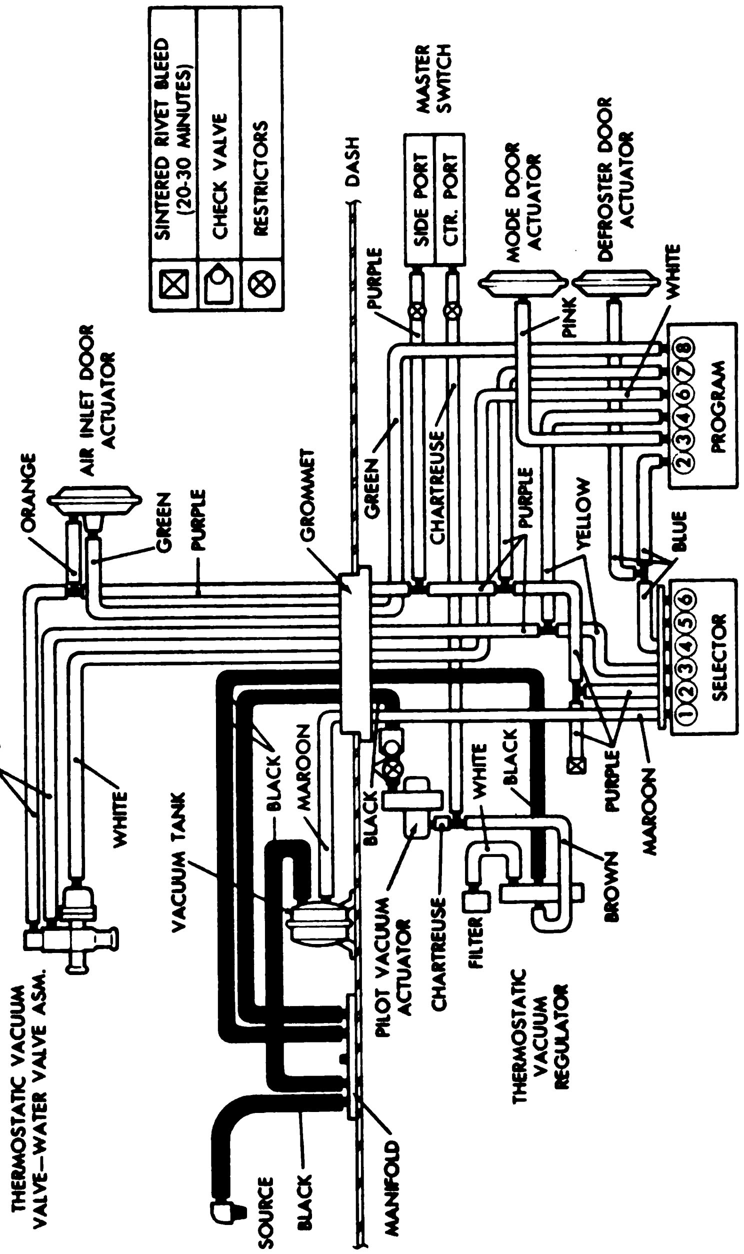

FIGURE 18 AUTOMATIC CLIMATE CONTROL VACUUM CIRCUIT DIAGRAM

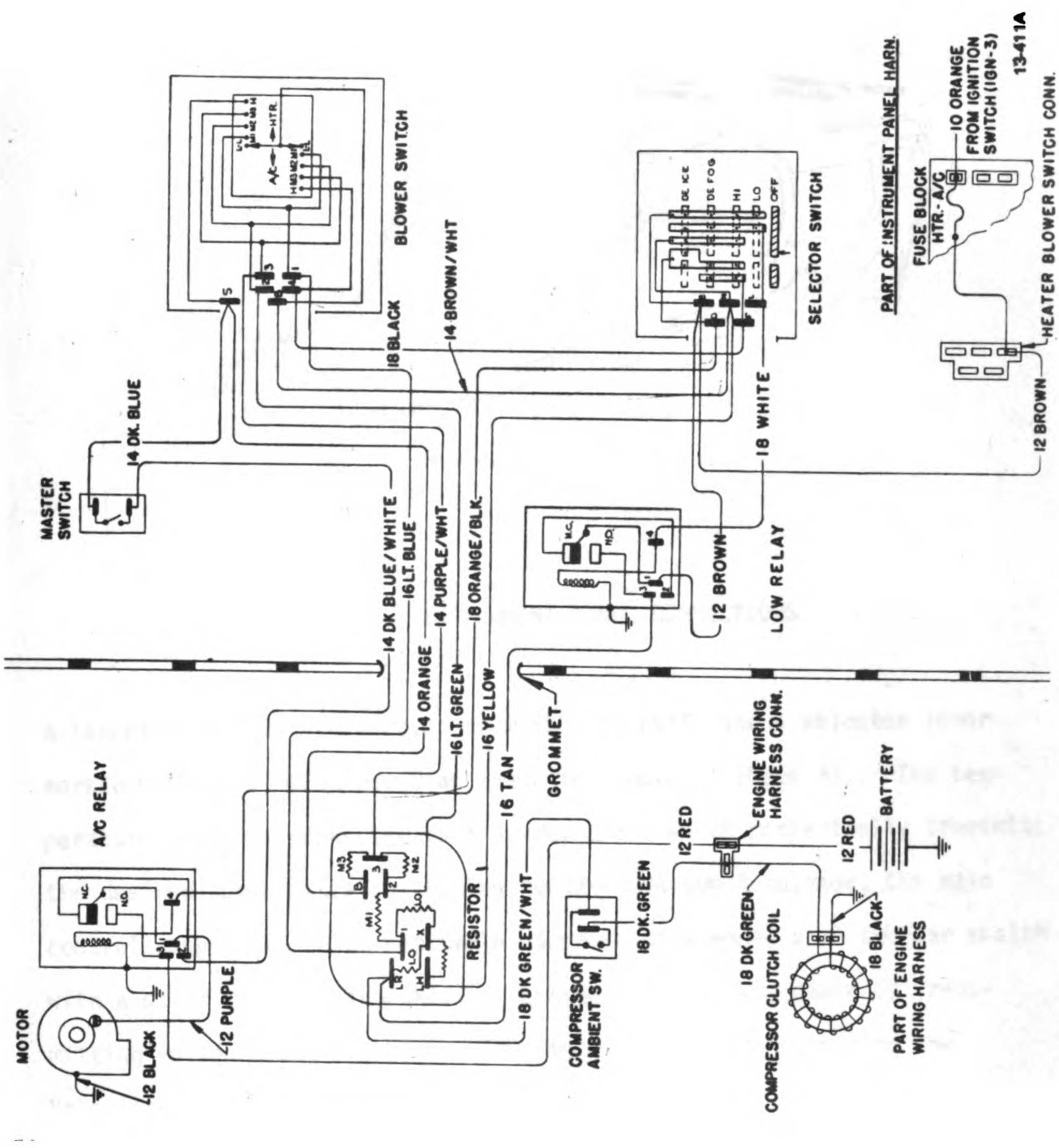

FIGURE 19 AUTOMATIC CLIMATE CONTROL ELECTRICAL CIRCUIT DIAGRAM

CONTROL PANEL

The Control Panel is mounted on the instrument panel to the left of the steering column as shown in Figure 20. It has two control levers,

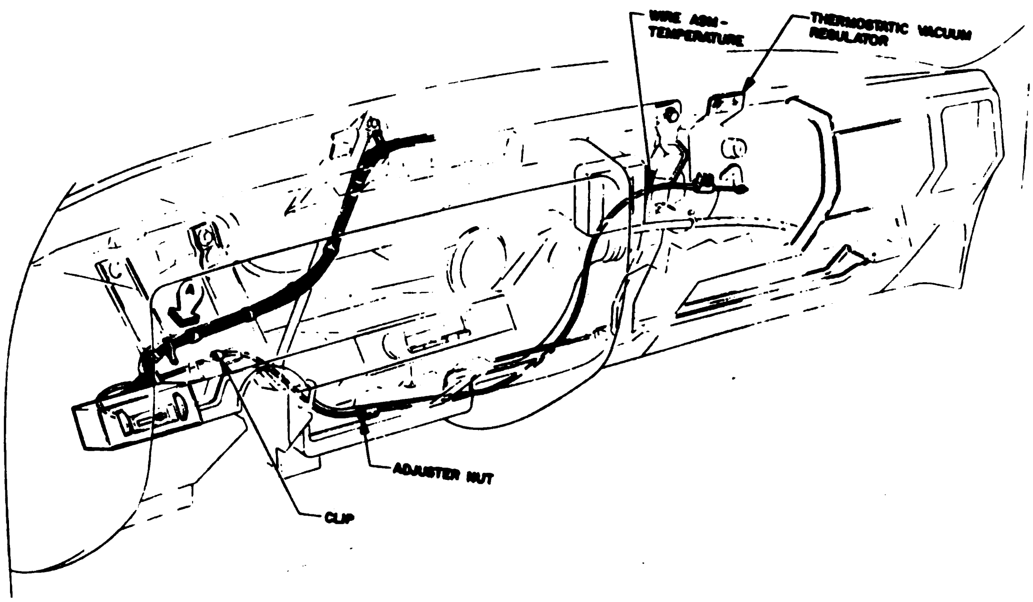

FIGURE 20 INSTRUMENT PANEL CONNECTIONS

a temperature lever calibrated from 65°F to 85°F, and a selector lever marked OFF-LO-HI-DEFOG-DEICE as shown in Figure 21 (Page 38). The temperature lever is connected to a Bowden cable which mechanically transmits the desired temperature to the Thermostatic Vacuum Regulator, the main control component. A Bowden cable consists of a wound wire tubular sheith with a stiff wire running axially through it. It is capable of transmitting motion along the wire. The Control Panel also contains the Selector Vacuum Switch and the Selector Electrical Switch. They are connected to the selector lever. They control the operation mode of the system.

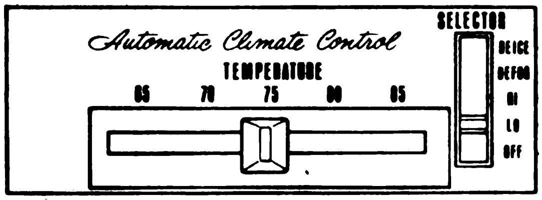

FIGURE 21 CONTROL PANEL

The system behaves as follows in each control lever position:

OFF - The system is inoperative with the blower off and outside air door closed.

LO - The system is under automatic temperature control with the fan in one of the five automatically selected low range speeds. System start-up delays are in effect. No high blower speed exists in maximum air conditioning in LO position.

HI - The system behaves much as it does in LO position except that the blower is in one of the five automatically selected high range speeds.

DEFOG - System is in HI range except heater mode is mandatory. The defroster door is also actuated so that the majority of the air goes to the windshield. Note, that air may be hot or cold as the system dictates.

DEICE - The system operates as in DEFOG range except that highest blower speed is mandatory. System start-up delays are by-passed only in DEICE position.

THERMOSTATIC VACUUM REGULATOR

The Thermostatic Vacuum Regulator is the main control component in the system. It receives information on desired temperature from the Bowden cable to the control, ambient air temperature, and breath level (also called in-car) air temperature and produces a controlled vacuum level output which governs the operation of the system.

The sensors are bi-metalic strips such as are commonly found in household thermostats. They are linked as shown in Figure 22 to the ball bleed valve. Ambient air is ducted to the Thermostatic Vacuum Regulator and passed over the ambient bi-metal strip. The ambient air passing through also automatically aspirates in-car breath air through a tube from the dash and over the breath bi-metal strip. The strips react to the ambient and breath air temperatures and being linked together, act in unison to force the ball valve to seat. The ball valve balances the force due to the difference between the atmospheric pressure and regulated partial vacuum and the net force of the bi-metal strips.

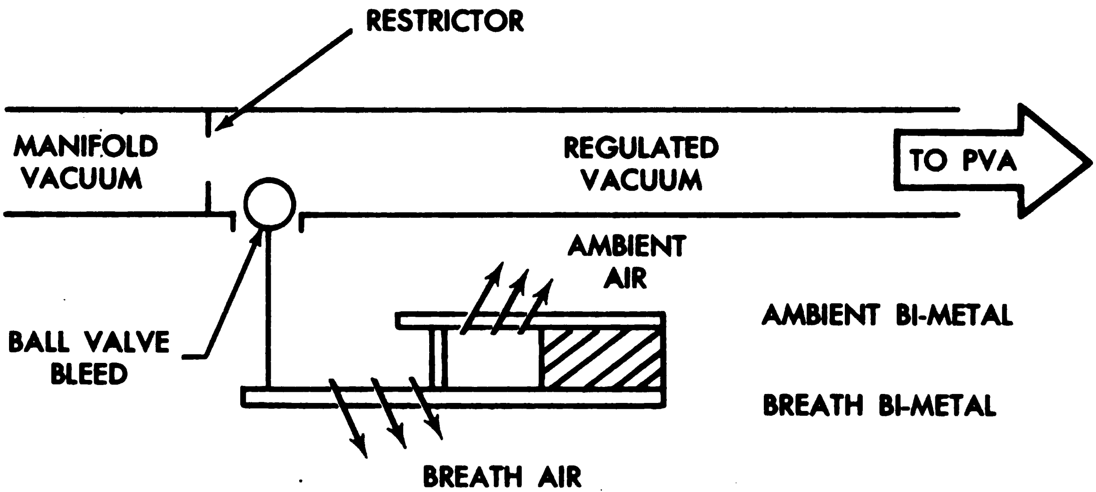

FIGURE 22 THERMOSTATIC VACUUM REGULATOR SCHEMATIC

Should the manifold vacuum rise, the ball valve would be forced off its seat farther thereby leaking more air and tending to maintain the regulated vacuum level. If the force from one bi-metal strip should rise, the ball valve would be forced farther into its seat causing less air leakage. This would result in a higher regulated vacuum level to keep the net force on the ball at zero.

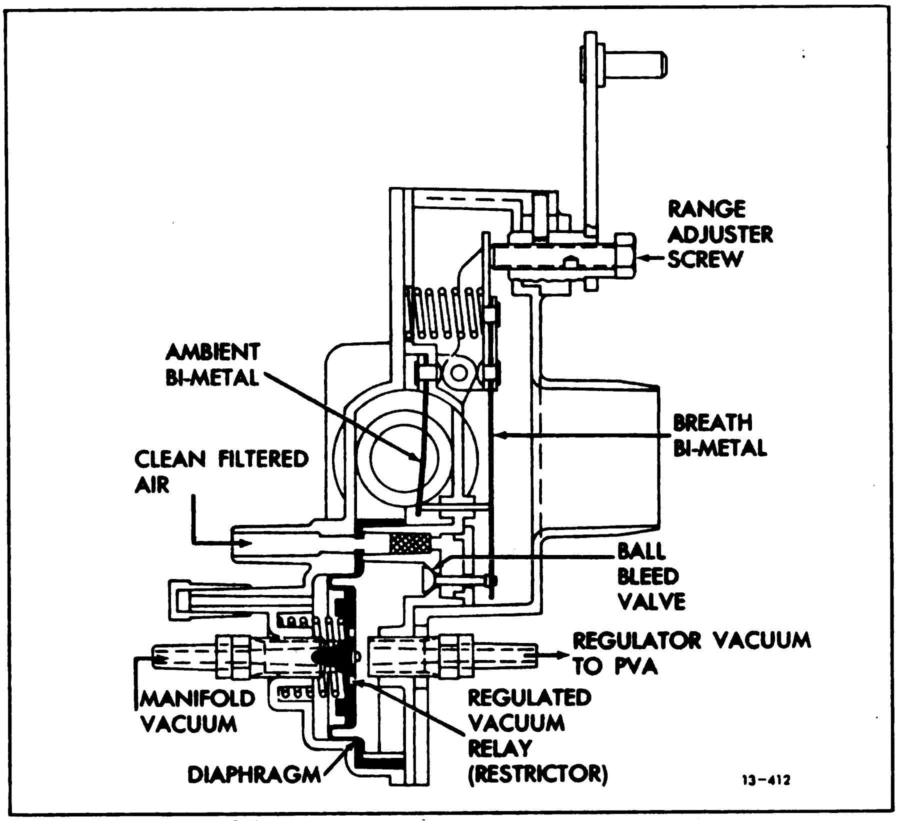

FIGURE 23 THERMOSTATIC VACUUM REGULATOR CROSS SECTION

Figure 23 shows a cross section of the Thermostatic Vacuum Regulator. The air that bleeds by the ball valve is filtered to keep the ball from being contaminated.

The Regulated Vacuum Relay is also integral with the Thermostatic Vacuum Regulator. Its function is to lock the regulated vacuum level during periods of low vacuum supply so that the system output does not change erroneously. When the manifold vacuum level (supply) drops below the regulated vacuum level momentarily, the relay seals the outlet port to the Piloted Vacuum Actuator.

The regulated vacuum is then applied to the Piloted Vacuum Actuator, the control element as shown in Figure 24.

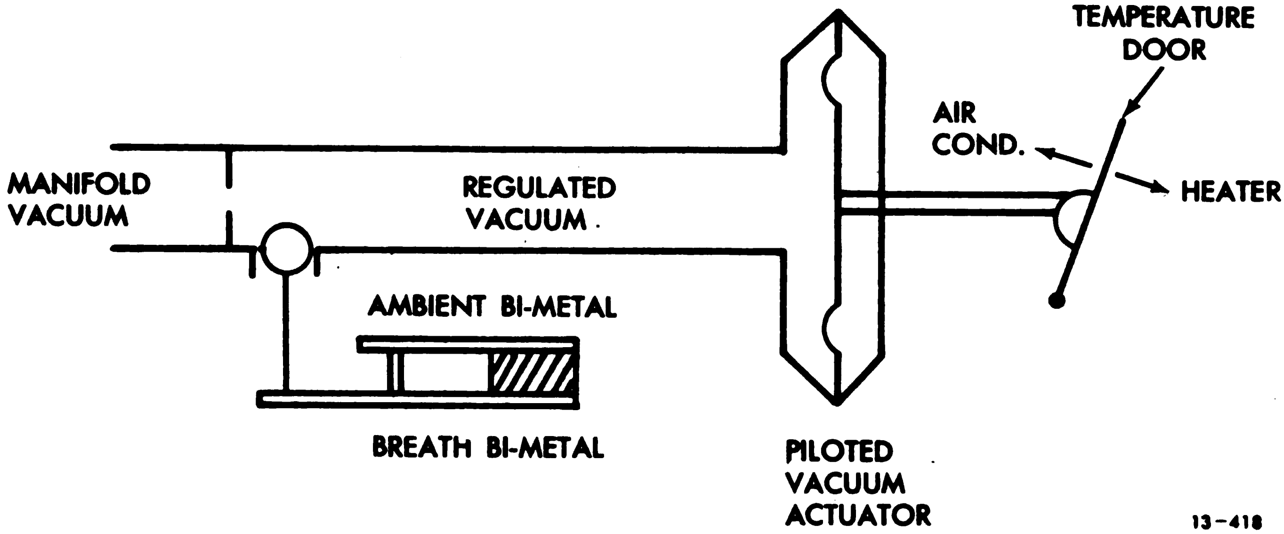

FIGURE 24 REGULATED VACUUM APPLICATION SCHEMATIC

PILOTED VACUUM ACTUATOR

The Piloted Vacuum Actuator balances a force due to the regulated vacuum from the Thermostatic Vacuum Regulator against a spring force giving a linear actuation which operates the temperature door as shown in Figure 24. It is not, however, a simple vacuum diaphram as shown in the figure. It is a two-diaphram unit. The regulated vacuum controls a pilot diaphram and engine vacuum is used to drive a power diaphram. The unit is shown in cross section in Figure 25 (Page 42). Regulated vacuum from the Thermostatic Vacuum Regulator determines the position of the pilot diaphram. Engine manifold vacuum is applied to the right-hand side of the power diaphram pulling it away from the pilot diaphram. This opens the bleed hole in the center of power diaphram allowing air to flow

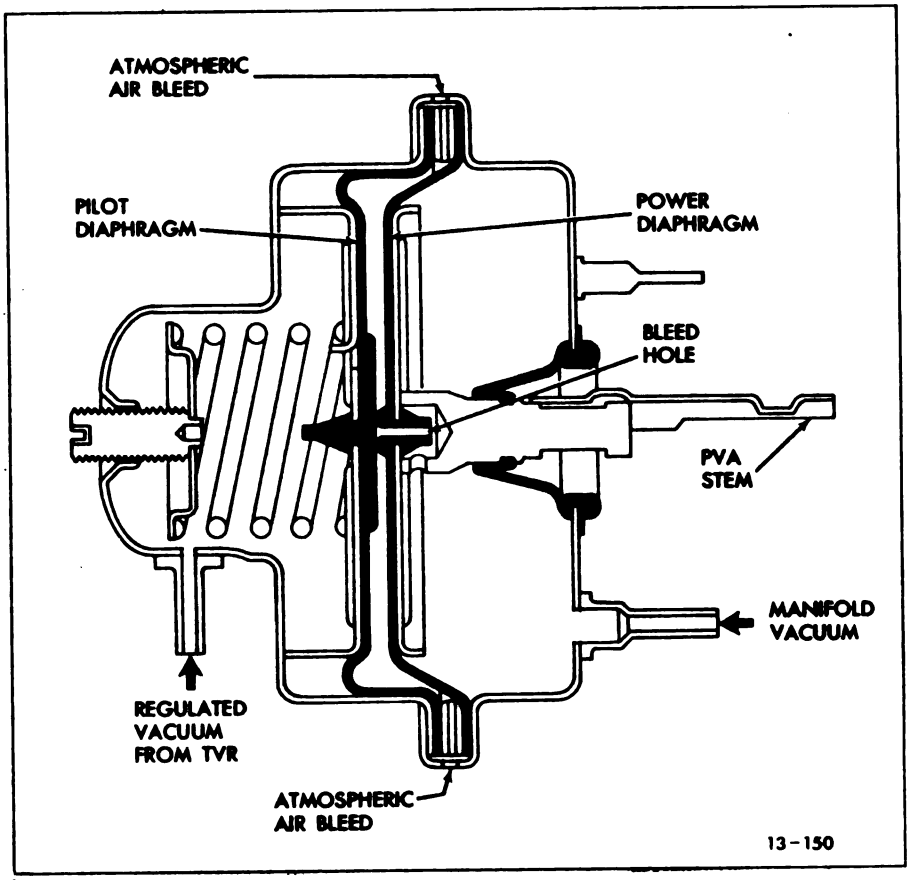

FIGURE 25 PILOTED VACUUM ACTUATOR

through the atmospheric air bleed ports and the bleed hole into the vacuum. When the atmospheric air and bleed hole flow rates are equal, the power diaphram stops moving. Should the power diaphram move away from the pilot diaphram, the bleed hole opens more allowing the power diaphram to move back. Should it move too far toward the pilot diaphram, the bleed hole is restricted and the manifold vacuum pulls it back. The power diaphram floats a small distance from the pilot diaphram and in the event that the pilot diaphram moves in response to changes in regulated vacuum level, the power diaphram follows.

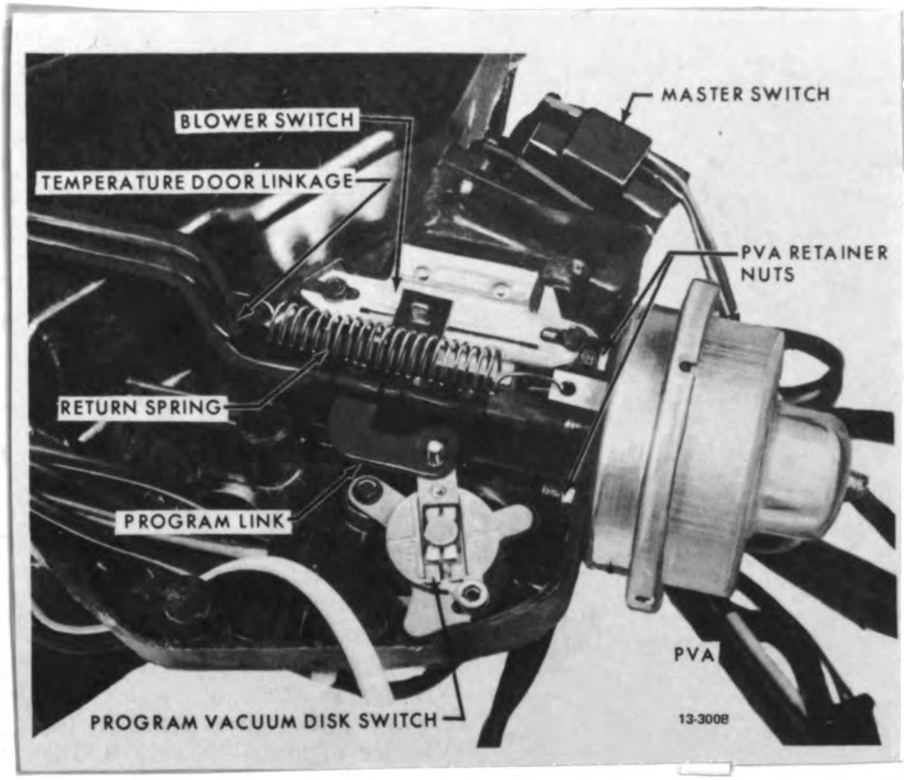

FIGURE 26 PILOTED VACUUM ACTUATOR INSTALLATION

Figure 26 shows the mounting of the Piloted Vacuum actuator. Its power diaphram drives the temperature door linkage and is also connected to the Program Vacuum Disk Switch and Blower Switch.

The Program Vacuum Disk Switch automatically selects the mode (heater or air conditioning outlets), changes the air inlet door, and shuts off the heater water. The Blower Switch controls the blower speed within the high or low range as selected by the driver.

<u>THERMOSTATIC VACUUM VALVE</u> (on Water Valve)

The Thermostatic Vacuum Valve opens to start the system in cold weather when the engine coolant reaches 120°F.

VACUUM MASTER SWITCH

The Vacuum Master Switch can be seen in Figure 26 (Page 43). It applies power to the blower circuit when vacuum is applied to it in any of the following ways:

a. The Thermostatic Vacuum Valve on the heater Water Valve opens when the engine coolant reaches 120°F and the control lever is in LO or HI.

b. The Thermostatic Vacuum Regulator senses the need to go to air conditioning mode as during hot weather and the control lever is in LO or HI.

c. The control lever is placed in DEICE.

AMBIENT SWITCH

The ambient switch, mounted in the blower inlet duct, is closed at temperatures above 35°F. It supplies power to the air conditioning compressor clutch whenever the system is on so that the air conditioning condenser will cool all incoming air to just above freezing to dehumidify it. At temperatures below freezing, the water from the air would freeze on the condenser, so the air conditioning system is turned off.

LOW RELAY

The Low Relay is actuated by the selector switch in any position except OFF. This relay controls the main power supply for the blower circuit.

A/C RELAY

The A/C Relay is operated either when the Blower Switch goes to highest air conditioning fan speed in HI range or the control lever is in DEICE position. It shifts the blower power supply from the Low Relay circuit to a circuit connected directly to the battery. This is done to by-pass most wire and contact resistances in the blower circuit thereby achieving highest possible blower speed.

VACUUM TANK

The Vacuum Tank, located in the engine compartment, stores engine vacuum to maintain system operation during periods of low vacuum supply.

OUTSIDE AIR DOOR

The outside air door, mounted in the blower assembly in the engine compartment, controls the source of air entering the system. It is designed to assume three positions.

a. OFF - Door closes out outside air (control lever in OFF)

b. Production Recirculation - Door opens partially to admit approximately 80% recirculated air and 20% outside air (automatically selected by the system at full air conditioning to improve cool-down performance)

c. Full Outside Air - 100% fresh air

DEFROSTER DOOR

The defroster door, located in the heater assembly, opens to pass about 80% of the heater air through the defroster outlets. It is designed to assume only two positions and should activate whenever the control lever is in DEF or DEICE.

MODE DOOR

The mode door, located in the heater assembly, directs air to either the air conditioning or heater ducts. It is designed to assume only these two positions.

TEMPERATURE DOOR

A door in the heater assembly, controlled by the Power Servo, controls the temperature of the air coming out of the air outlets. This door can assume a position from full heated air to full cooled air.

WATER VALVE

The Water Valve, mounted in the engine compartment, is in the engine coolant to heater core line. It is actuated only when the system goes to full air conditioning and it stops engine coolant flow to the heater to improve cool-down performance.

SINTERED BLEED RIVET

When the engine is stopped and the engine coolant cools down, the vacuum is blead from the system by the Sintered Bleed Rivet to avoid immediate system start-up. The bleed down time is about 12-35 minutes.

VACUUM RESTRICTORS

There are several Vacuum Restrictors in the system. There is one in each part to the Master Switch to introduce a 15-30 second delay in blower start-up each time the blower is turned on to allow the system to drive to the position it will run in after the system starts. There is another restrictor in the engine vacuum line to the Piloted Vacuum Actuator.

BLOWER RESISTORS

The Blower Resistors are a set of electrical resistances, switched sequentially into and out of the blower motor circuit to change the blower speed.

The following operation sequences are included to assist the reader in understanding the operation of the system. They are meant by no means to include all operational possibilities.

CASE 1

Initial Conditions

The car has been exposed to a temperature of 20°F for a period of time sufficient to allow the entire vehicle to stabilize at that temperature.

Sequence of Operations

1. The driver enters the car, starts the engine, turns the Automatic Climate Control temperature lever at 72°F and the control lever at HI, and drives off.

2. Vacuum has been supplied to the system so the Thermostatic Vacuum Regulator drives to full heat during the initial 15-30 second delay. Since the system is at full heat, the immediate start-up feature for air conditioning is by-passed.

3. At some time the engine coolant warms to 120°F and the Thermostatic Vacuum Valve on the Water Valve opens. This applies vacuum to the door actuating diaphrams and Master Switch as directed by the system. The Master Switch is delayed 15-30 seconds by the restrictor plugs in its vacuum lines to allow the doors to get into position. The fan starts in highest speed.

4. As the car warms to near the desired temperature, the system starts to throttle back by moving the temperature door to a more moderate position and reducing the fan speed.

5. As the system senses that the desired temperature has been reached, it is in low fan speed and the temperature door is to produce some warm outlet temperature to keep the interior warm. It is normal for this system to overshoot the desired temperature and cycle about it a few times as the system adjusts.

6. The system stabilizes at the desired temperature and continues making adjustments to maintain that temperature.

CASE 2

Initial Conditions

The car has set in the sun for a period of time at an ambient temperature of 90°F. The interior of the car has reached a high temperature.

Sequence of Operations

1. The driver enters the car, lowers the windows, starts the engine, sets the control lever to HI, and drives off.

2. Vacuum is applied to the Thermostatic Vacuum regulator and, sensing the need for maximum cooling, it moves in that direction. As the system goes to air conditioning mode, vacuum is applied to the Master Switch and appropriate diaphrams thereby by-passing the start-up delay.

3. After 15-30 seconds, the Master Switch closes starting the fan in high speed. Since the system is at maximum cooling, the Heater Water Valve is shut off and the inlet air door is in the recirculate position.

4. The driver closes the windows and the interior starts to cool.

5. As the system senses that the in-car temperature is approaching the desired temperature, the system begins to throttle back. The outside air door goes to full outside air, the fan speed reduces, the temperature door goes toward center position, and the heater Water Valve opens.

6. As the desired in-car temperature is reached, the fan speed is in low and the temperature door is situated to deliver cool air to the interior to maintain the desired temperature.

III. PONTIAC AUTOMATIC TEMPERATURE CONTROL

The Automatic Temperature Control was first installed by Pontiac in 1967. The system was and still is unique in design in General Motors. It was designed by Delco Radio.

The Automatic Temperature Control is an electro-mechanical feedback servo system. It uses electrical sensing elements and an electric motor as the main control element. In this respect, it is unlike any other General Motors automatic air conditioning system. That is, it does not use regulated vacuum as a proportional control power source. It does, however, use vacuum to actuate door diaphrams. This makes the system much less sensitive to variations in engine load and speed conditions.

The system supports the following features to attain and maintain a desired temperature level rapidly and accurately:

1. Outlet air temperature - from full heater air to full cooled air.
2. Fan speed - five unique fan speeds in each of two ranges.
3. Mode - outlet air distribution
    a. Heater
    b. Bi-level - air out both heater and air conditioning outlets.
4. Inlet air distribution
    a. 100% outside air
    b. 50% outside air - 50% inside air
    c. 100% inside air
5. Dehumidification - at ambient temperatures above 35°F.

6. System start-up delays

    a. Cold weather start-up delayed until heater core has heated to deliver warm air.

7. DE-ICE - Start-up delays by-passed and system drives to full heat, high speed fan.

8. Heater water shut-off - to enhance maximum cooling performance.

9. Consistent start-up - system drives to near center position whenever power is turned off so that it always starts in low speed.

Again, the information on Figure 2 (Page 9), is indicative of the information flow in the Automatic Temperature Control.

The following figures are vacuum and electrical circuit diagrams. Reference to these figures will aid understanding the interrelationships between the components as described subsequently.

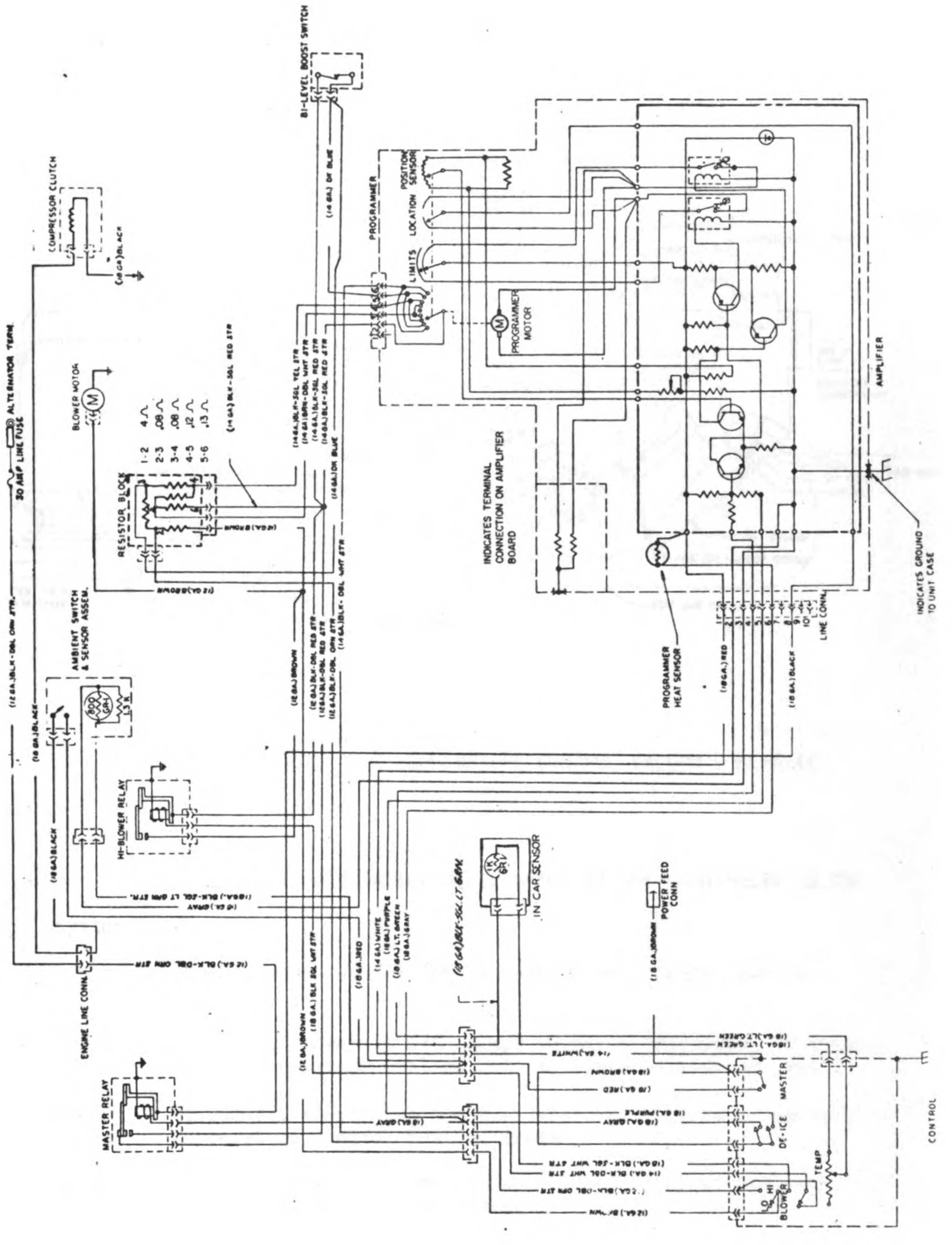

FIGURE 27 AUTOMATIC TEMPERATURE CONTROL ELECTRICAL SCHEMATIC

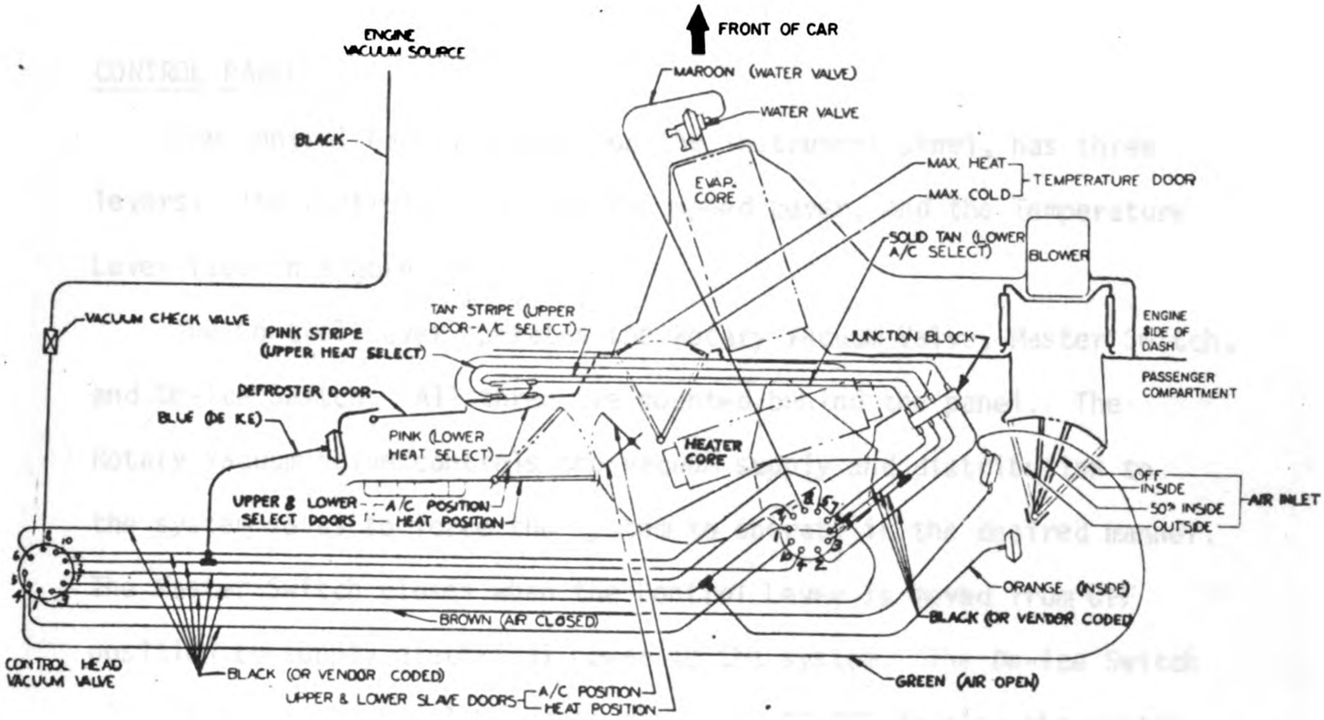

FIGURE 28 AUTOMATIC TEMPERATURE CONTROL VACUUM SCHEMATIC

The following is a detailed description of the components in the system.

The system behaves as follows in each control lever position:

OFF - Electrical power is off except to drive Programmer to center position. Vacuum applied only to close outside air door.

NORMAL - Vacuum and electrical power is applied. System in automatic temperature control and fan speed.

INSIDE - System acts as in NORMAL except air is recirculated from inside car to enhance performance.

DEFOG - System acts as in NORMAL except heater mode and defroster outlets are selected.

DE-ICE - System is no longer in automatic control, high fan speed, and full heat are forced. System start-up delays are by-passed.

CONTROL PANEL

The Control Panel, mounted on the instrument panel, has three levers: The Control Lever, the Fan Speed Lever, and the Temperature Lever (see in Figure 29).

The Control Lever operates the Rotary Vacuum Valve, Master Switch, and De-Ice Switch. All three are mounted behind the panel. The Rotary Vacuum Valve controls the vacuum supply and distribution to the system so as to force the system to operate in the desired manner. The Master Switch closes when the Control Lever is moved from OFF position to supply electrical power to the system. The De-Ice Switch closes when the Control Lever is placed in DE-ICE forcing the system to full heat and high fan speed.

The Fan Speed Lever drives the blower switch allowing the driver to

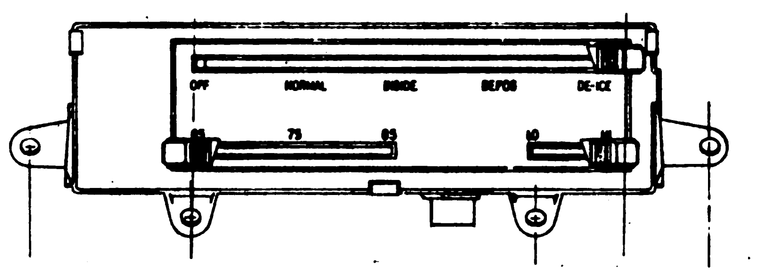

FIGURE 29 CONTROL PANEL

select a high or low range of fan speed.

The Temperature Lever drives the Variable Resistor Temperature Control, also mounted behind the panel. This resistor is the input to the control system which sets the desired temperature. The Temperature Lever is calibrated from 65°F to 85°F.

SENSORS

The system has three sensors: the in-car, the ambient, and the position sensor. The in-car and ambient sensors are thermistors, temperature sensitive resistors and the position sensor is a potentiometer. The sensing elements in the Automatic Temperature Control are the same as those in the Oldsmobile Comfortron.

The ambient sensor is mounted in the air inlet duct along with the Ambient Switch as shown in Figure 30.

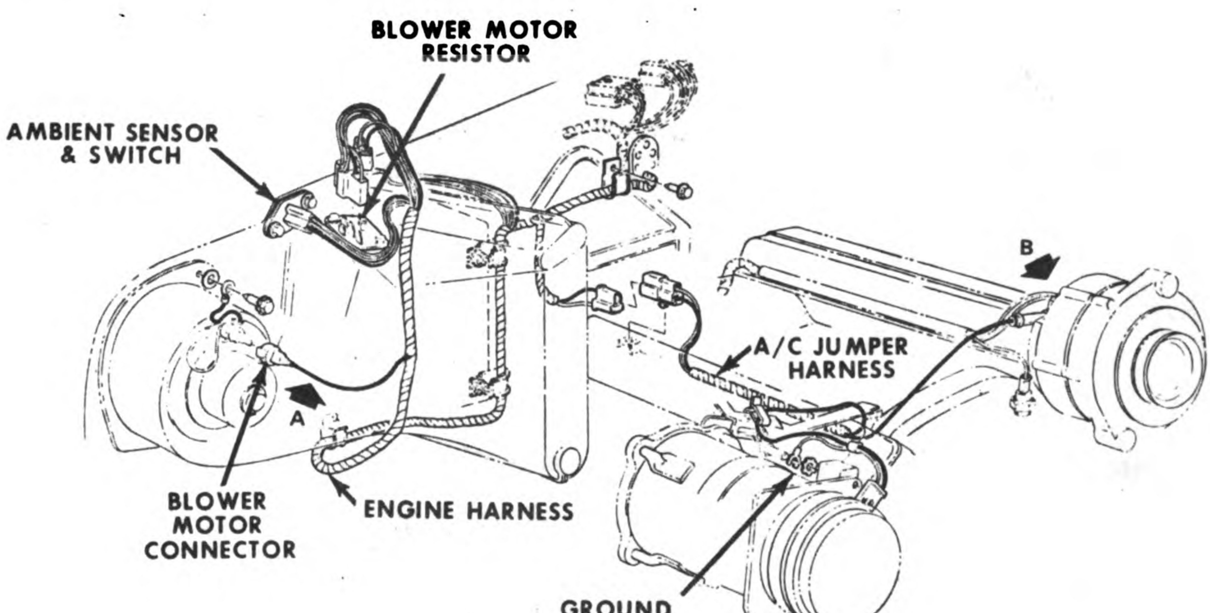

FIGURE 30 ENGINE COMPARTMENT CONNECTIONS

The in-car sensor is mounted on the passenger-side of the instrument panel as shown in Figure 31. Air is drawn through the Aspirator and Hose by the air movement in the ducts. This air is drawn from the interior of the car and past the in-car sensor.

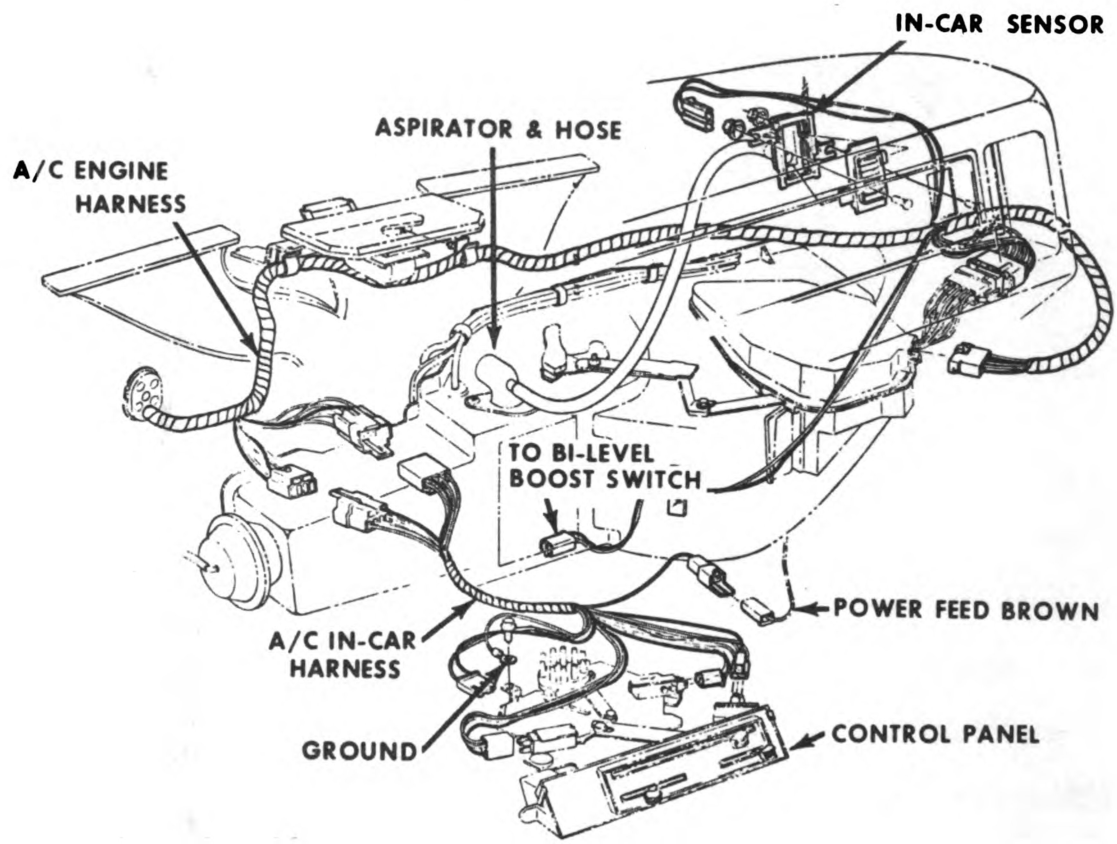

FIGURE 31 INSTRUMENT PANEL CONNECTIONS

The position sensor is mounted in the Programmer connected to the output linkage. Its output is analogous to air outlet temperature.

PROGRAMMER

The Programmer is the main control element in the system. It is mounted on the air conditioning heater assembly under the dash, as shown in Figure 32 (Page 56). It contains the electric motor, amplifier, fan speed, and position switches, and position sensor.

The amplifier is a four transistor, Direct Current amplifier. Its inputs are the sensor string and the temperature control setting.

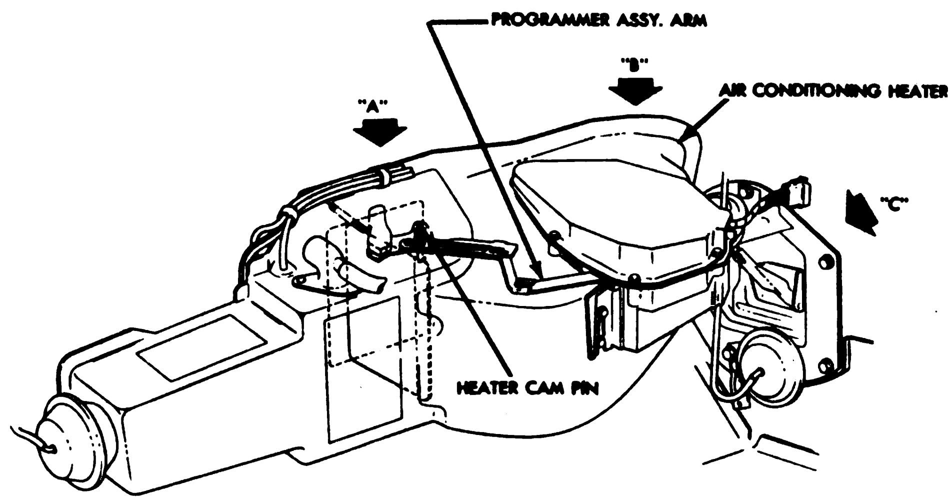

FIGURE 32 PROGRAMMER INSTALLATION

It also has inputs to drive the system to full heat in DE-ICE position. Its output drives the motor.

The motor positions the temperature through a gear train and linkage seen in Figure 32. The fan speed switch is also connected to the motor output along with the limit and location switches. The blower switch automatically sets the blower speed in one of five speeds in either high or low range as determined by the driver. The limit switch stops the motor at full travel to prevent it from being stalled. The position switch returns the Programmer to about the center position between heater and air conditioning every time the system is turned off.

The position sensor is also driven by the motor output as described before.

The Programmer Heat Sensor is also in the Programmer. It protrudes into the heater case near the heater core. This unit produces the start-up delay during cold weather. When cold, its resistance is high enough to hold the Master Relay off. As the engine coolant warms, the heater core and consequently the sensor, its resistance drops until, when the heater core is warm enough to warm the car, the system comes on. In warm weather, the sensor is already warm, so that the system starts immediately.

MASTER RELAY

The Master Relay delivers the electrical power to the system when activated. When deactivated, it applies power to the location switch to drive the Programmer to neutral position.

HIGH BLOWER RELAY

The High Blower Relay is activated by the Fan Speed Lever on the Control Panel. It places the fan speed in high range.

AMBIENT SWITCH

The Ambient Switch removes power from the Compressor Clutch at ambient temperatures below 35°F when the Compressor is not needed to cool the air.

BI-LEVEL BOOST SWITCH

The Bi-Level Boost Switch increases the fan speed when the system in in bi-level mode to accommodate the increased air outlet area.

RESISTOR BLOCK

The Resistor Block is a set of electrical resistances which are switched into and out of the blower circuit to change fan speeds.

ASPIRATOR

Whenever air is forced through the heater case, the Aspirator draws air through the in-car sensor in the dash panel from the interior of the car.

AIR INLET DOOR

The Air Inlet Door assumes four positions to regulate the relative amounts of outside air and recirculated air entering the system. It is located in the heater assembly.

UPPER and LOWER SELECT DOORS

The Select Doors operate side by side on the same hinge line. In heater mode, they both direct air to the heater outlets and in air conditioning mode, they both direct air to the air conditioning outlets. In bi-level mode, the Upper Door directs air to air conditioning outlets and the Lower Door directs air to the heater outlets so that air comes from all outlets.

SLAVE DOORS

The Slave Doors are operated by the Select Coors and operate independently of each other. In bi-level, they are in opposite ends of travel as are the Select Doors. They help equalize distribution to all outlets.

DEFROSTER DOOR

The Defroster Door is actuated to direct air from the heater ducts to the defroster outlets when the control is in DEFOG or DE-ICE.

WATER VALVE

The Water Valve is shut off automatically so that engine coolant will not flow to the heater core when the system is at maximum cooling.

As in previous chapters, for the purpose of greater understanding of the operation of the system, the following operating sequences are included.

CASE 1

Initial Conditions

The car has been exposed to a temperature of 20°F for a period of time sufficent to allow the entire car to stabilize at that temperature.

Sequence of Operations

1. The driver enters the car, starts the engine, turns the Automatic Temperature Control Lever to NORMAL, moves the Fan Speed Switch to HI, sets the Temperature Lever to 70°F, and drives off.

2. The Programmer heat sensor is initially at 20°F thereby prohibiting the Master Relay from closing and applying power to the system. As the engine coolant flowing through the heater core warms, the Programmer sensor resistance eventually drops enough to activate the Master Relay, starting the system.

3. The Programmer, having parked at mid-range as it always does, begins to drive toward full heat position. This is done to allow cold air to be purged from the system slowly on low blower and so that the blower speed increases gradually to high blower speed and maximum heat and starts to warm the car.

4. As the interior approaches the desired temperature, the system starts to throttle back. The Temperature Door moves toward center position and the fan speed reduces a step at a time until the fan speed is low and the outlet temperature is warm enough to maintain the desired temperature.

CASE 2

Initial Conditions

On a mild, 50°F morning, the driver starts out on a long trip with the Automatic Temperature Control on. The system has warmed the car to 70°F as described in Case 1.

Sequence of Operations

1. As the ambient temperature warms, the system constantly adjusts to maintain the desired temperature.

2. At a preset Programmer position, when the air coming from the outlets is regulated at a neutral temperature as when the ambient temperature is near the desired temperature, the system goes to bi-level mode and the Bi-Level Boost Switch increases the fan speed to compensate for the increased outlet area. Bi-level is a transitional mode between heater and air conditioning.

3. The ambient temperature continues to rise and the outlet temperature is adjusted lower and lower until at another preset Programmer position, the system changes to air conditioning mode.

4. The system continues to adjust to maintain the desired temperature.

IV. PRODUCTION INSTALLATION ADAPTABILITY

From the standpoint of profit, there are three considerations to building a product, especially one as large as an automobile, material costs, labor costs, and after-sale service costs. It was the subject of a discussion of some length in the Introduction as to why the material costs might not be a very good basis for comparison of the three automatic temperature control systems under consideration. Basically, it is because the systems are so different in the ways that they approach the general aim of temperature control. It seems unfair to penalize one system because the engineers who designed it insisted upon certain features which cost money when other engineers decided that the same features were not worth the cost penalty in another system.

Now, it is not the object of this dissertation to decide which system is best. It is to compare the systems on some basis upon which the systems are comparable. Labor cost or labor time is one reasonable basis of comparison. The two are directly related by labor price.

This assertion requires some substantiation. To a limit, it costs little to have production labor install a wiring harness with an extra wire or hose in it or to install a component which is designed to support a different feature in the system.

It is possible that the systems could be modified, still maintaining the basic designs and operating principles so that all three systems would support identical features. Then material costs would be a good index of comparison. Even then, it is doubted that the labor costs would be substantially different from their present values.

To make a comparison of labor costs, it would have been possible to ask Buick, Oldsmobile, and Pontiac to report their respective standard labor figures for their automatic temperature control systems respectively. The comparison might have been made, but it is likely that the figures are based on different standards from the different organizations. A very convenient situation exists with General Motors Corporation. One division, General Motors Assembly Division, has as its sole responsibility, the assembly of General Motors automobiles. The Kansas City plant builds Buicks, Oldsmobiles, and Pontiacs for instance. The best comparison of production labor can obviously be made from the figures of one division that produces all three units.

The following figures were obtained from General Motors Assembly Division central office. The numbers are standard labor burden allowance totals. Minimum and maximum figures are shown. The variation is due to difference in individual models.

TABLE 3

TOTAL STANDARD BURDEN ALLOWANCE PER SYSTEM

	Total Standard Burden Allowance		
Car	Minimum	Maximum	Mean
Oldsmobile	52.20	61.49	56.84
Buick	52.22	53.42	52.82
Pontiac	56.24	58.36	57.30

The numbers represent standard burden minutes.

The following table lists the number of components, electrical connections, and vacuum connections. It is to be noted that the Oldsmobile system has major control system components constructed as separate units. It might be expected that the other systems would have fewer components over all. However, the differences in design in the systems comes into play. It would be expected that the Pontiac system would have

TABLE 4

NUMBER OF COMPONENTS AND CONNECTIONS PER SYSTEM

Car	Components	Electrical Connections	Vacuum Connections
Oldsmobile	11	14	23
Buick	9	8	25
Pontiac	10	18	20

substantially fewer vacuum connections, for instance, than the others because it uses an electric motor to control the system while the others use regulated vacuum. But it has very nearly as many as the other by engineering design. For instance, it uses some double acting diaphrams, which are forced both ways by switching vacuum from one port to the other. The other system employs only diaphrams which are forced one way by vacuum and the other way by a spring.

The labor costs compare favorably with the number of components and connections. The Buick system is lowest in standard burden and lowest in operations necessary to construct it. This does not include the operations necessary to produce the components. If more money is spent having the components built up into units, it will naturally cost less to assemble the system.

There is one advantage in having a system in a single package. It is easier to install for there is less to do. But, it may be difficult to find a place for one large package while many small compoents can be located in separate locations. Both conditions will have implications to after-sale service also.

It was found, while interviewing repair personnel at the Kansas City plant, that repair of the systems at the assembly plant is an individual business. They report little engineering instruction in repair procedures. Often engineering changes appear in cars at the end of the assembly line of which the repair personnel have no knowledge. It seems unreasonable to expect repair people to repair units which are foreign to them.

Care was taken to interview repairmen on an individual basis so that a broad unconnected set of responses would be obtained. All agreed that they found the systems easiest to repair in the order:

1. Oldsmobile Comfortron
2. Buick Automatic Climate Control
3. Pontiac Automatic Temperature Control

It was found that the speed of system response was an important factor in the above listing. That is, it is easier to repair a system which responds rapidly.

By far, the most often reported problem with inoperative systems at production repair stations was inaccurate assembly. Off, loose, torn, and kinked hoses and electrical connections are far and above the most common faults. Therefore, a system with fewer connections would be judged to be desirable.

The Pontiac system was worst for production repair to a large degree because its components were so difficult to reach. The Pontiac instrument panel condition is extremely tight and removing the control is a long and complicated job. The control panel is a difficult unit to remove in all cases.

Only the normally expected rate of unit failures was reported. A certain number of defective components is to be expected. No particular component was cited as having an unusually high failure rate.

By far, the most often mentioned problem areas at production repair areas were assembly quality problems. Nonassembly, misassembly, and poor assembly are the problem areas.

One of the positive attributes of a system is that there are few assembly operations to be made at the final assembly operation.

Unfortunately, no good index of comparison was found to compare the systems with respect to production characteristics. The following chapter discusses the service characteristics of the system.

V. SERVICEABILITY

Post-sales warranty service has come to be an important consideration in the automotive industry with extended warranty periods now in general effect. There are several points to be made about the service characteristics in comparing the three automatic air conditioning systems of this work.

An attempt was made to obtain Service Department data about the systems in question. The Service Departments at Oldsmobile, Buick, and Pontiac all have a more or less standard system of accounting service data so that the above information is readily available through proper channels. It became likely, after a period of investigation, that raw service data was probably a poor indication of actual failures in customer service.

Consider the following in evidence of this fact. A search of Oldsmobile's computer printed tabulation of dealer warranty claims indicates that the high warranty components in the Comfortron system were the major components such as the Transducer, Power Servo, and Control Panel. There is almost no indication of vacuum hose or electrical connection problems. Yet all indications from all persons interviewed are that vacuum hoses and electrical connections are the major problem areas.

Some probable reasons for this phenomenon have been found. The automatic temperature control systems are fairly unique in the automobile in that they are so complex and that their principles of operation are not at all widely understood. Consequently, the time necessary to locate the source of nearly any malfunction is abnormally high when compared to the time necessary to locate an engine problem for instance. The dealer is not reimbursed for troubleshooting a malfunction. In the event that a vacuum hose was disconnected, locating the problem may take a great amount of time while fixing it may take seconds.

Another thing seems obvious. Service repairmen do not understand any of the automatic air conditioning systems. Numerous examples have been found where dealer personnel have spent literally days attempting to locate a malfunction in one of the automatic systems. When a company engineer responsible for the systems has worked on some of these automobiles, it has rarely taken over an hour to find and rectify the problem. This is not to say that repairmen can or should be as familiar with the systems as the engineers must be. But it must be true that these repairmen should be instructed in repairing the systems and should be provided with more adequate service reference material.

Some service training programs do exist. These programs can give basic instruction on the principles of operation of the systems which is undeniably valuable. But, the repairman who must fix only a few systems a year requires a source of reference. The service manuals vary in completeness. The Pontiac manual has the least information. The section on the automatic temperature control is 12 pages long. It contains one paragraph of description of the system. The rest of the material consists of "remove and replace" information or adjustment procedures. No troubleshooting information is offered.

The Oldsmobile Service Manual devotes 21 pages to the automatic system. The information includes a description of each component, its function, and its location. Also present is a section on removal and replacement of components and a troubleshooting chart. This chart is in flow diagram format which leads the repairman through a sequence of steps leading, hopefully, to the malfunction. This method of troubleshooting has the fault that it is not always easy to check the conditions indicated. For instance, it may be hard to check the vacuum level at a certain point because that point is hard to reach. Indeed, the very act of checking a condition may introduce the opportunity for a hose to be disconnected or misplaced.

The Buick Service Manual is by far the most complete of the three. It contains 56 pages concerning the automatic climate control. This section was written as a joint effort of Buick and Harrison Radiator, the designer of the system. The text describes the components in the system and explains how the system works. The usual repair information is present. The troubleshooting guide is presented in a list format. The list presents malfunctions and an enumeration of the probable causes and proper corrective steps to be taken.

It was stated previously that there were service advantages to single package systems. If the entire system is tied up in one package, the problem of locating a malfunction is greatly reduced especially if the package is easy to locate and remove. This, of course, makes it necessary to have repairmen trained in repairing the package for without this, the cost of simply replacing an entire package would be prohibitive. As it is now, repair within a component in any one of the systems is not generally recommended. The Pontiac manual does allow repairs within the Programmer, but only to the extent of replacing the Amplifier or Motor for instance.

A single package system is under development by Delco Radio which is good for a point of explanation. This system would almost entirely mount behind the control panel in the instrument panel with a minimum of components outside the package. The manner in which all car instrument panels are constructed now makes it extemely difficult to remove components from the location especially on cars with air conditioning, radio, and other accessories. A repair in this area is hard to affect unless the package is relocated or the instrument panel is redesigned to make removal and replacement of components easier.

The following chapter is a list of some conclusions and recommendations which are a result of this research.

VI. CONCLUSIONS AND RECOMMENDATIONS

It seems appropriate at this point to draw some important points from the text and recommend future courses of action and design goals. It is unfortunate that no sound, quantative basis of comparison was found on which to compare the three automatic temperature control systems considered in this report. The conclusions and recommendations herein are of a qualitative nature. It will be obvious that each conclusion is based upon textural material.

1. Each of the three systems attains the same basic design goals. All accomplish with comparable speed and accuracy the task of attaining and maintaining a desired, comfortable in-car temperature.

2. Though no numerical data could be found to substantiate the fact, circumstantial evidence points strongly the fact that vacuum and electrical problems constitute the largest single problem areas. The following steps are recommended as possible ways to reduce the problem.

    a. Employ improved vacuum connections which connect positively and securely.

    b. Use more and better gang connections or keyed connections to allow only proper assembly.

    c. Use a color keying or size coding scheme to promote c correct assembly and reassembly in the event that the system is disassembled for any reason.

    d. Reduce the number of individual connections by ganging hoses together. This may not be economically feasible now, but in the event that some redesign is made desirable by other considerations, this could also be done.

e. Combine components into single assemblies to eliminate interconnections. Again, this could be done in the course of general redesign as above.

f. Revise component locations and hose routing to reduce the possibility of kinked and squashed hoses.

3. The service manual information is inadequate, at least on the Pontiac and Oldsmobile Systems. It is recommended that the service manual be carefully rewritten, with the aid of Delco Radio, if possible, to include more pertinent information to allow servicemen to understand the operation of the systems.

4. It is suspected that warranty figures tell an incomplete or, at worst, an untrue story about the in-service failure areas. It would be desirable to have a source of better feedback information. None is known at present.

5. Relocate components or otherwise provide for better component accessability. This especially applies to instrument panel mounted components. The control panels, for instance, are very difficult to remove and replace. It would be especially convenient if the instrument panel components could be accessed and removed from the front of the panel. This would require a major change in panel design but would be valuable for service of all instrument panel components.